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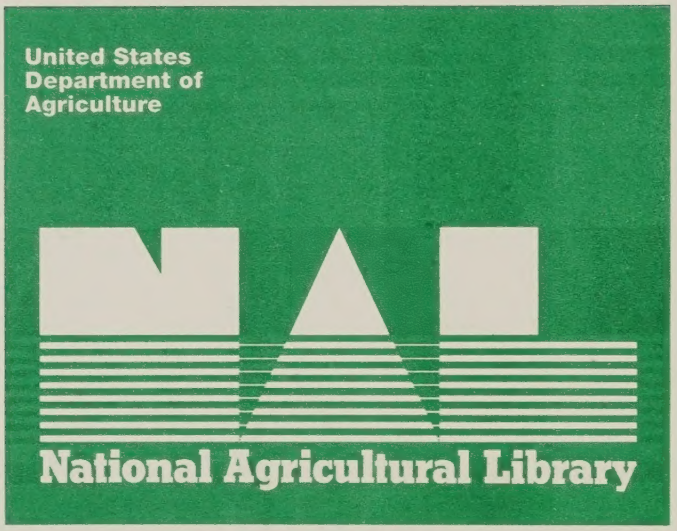
1997–02

August 1997

Silverleaf Whitefly

1997 Supplement to the Five-Year National Research and Action Plan:

Progress Review, Technology Transfer, and New Research and Action Plan (1997–2001)


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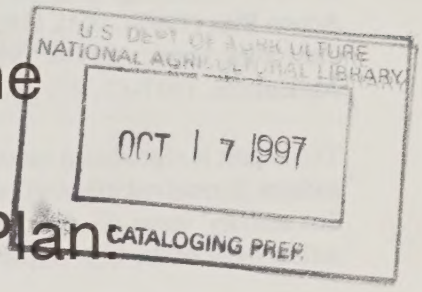
**Agricultural
Research
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Silverleaf Whitefly

1996 Supplement to the Five-Year National Research and Action Plan:



Progress Review, Technology Transfer, and New Research and Action Plan (1997–2001)

(Formerly Sweetpotato Whitefly, Strain B)

Fifth Annual Review, San Diego, California, January 28–30, 1997

In cooperation with USDA-Agricultural Research Service, USDA-Cooperative State Research, Education, and Extension Service, State Agricultural Experiment Stations, USDA-Animal and Plant Health Inspection Service, USDA-Extension Service

Henneberry, T.J., N.C. Toscano, T.M. Perring, and R.M. Faust, eds. 1997. Silverleaf Whitefly, 1997 Supplement to the Five-Year National Research and Action Plan: Progress Review, Technology Transfer, and New Research and Action Plan (1997–2001), Fifth Annual Review, San Diego, California, January 28–30, 1997. U.S. Department of Agriculture, 1997–02, 272 pp.

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Editors' Comments

Henneberry, T. J., N. C. Toscano, T. M. Perring, and R. M. Faust (eds.) 1997 Silverleaf Whitefly Supplement to the 5-Year National Research and Action Plan: Progress Review, Technology Transfer and New Research and Action Plan (1997-2001). San Diego, CA, January 28-30, 1997.

This document summarizes the accomplishments resulting from the first 5-Year National Research and Action Plan for Sweetpotato Whitefly (sweetpotato whitefly Strain B = silverleaf whitefly), (U.S. Department of Agriculture Publication, Agricultural Research Service, ARS-107, June 1992). It also describes mechanisms for current and future technology transfer and outlines future research priority goals for the years 1997-2001. The sweetpotato whitefly, *Bemisia tabaci* (Gennadius), Strain B was redescribed in 1994 as *B. argentifolii* Bellows and Perring with a suggested common name of silverleaf whitefly. Internationally, the nomenclatural validity for *B. argentifolii* remains controversial. However, the seriousness of *B. tabaci* Strain B as an international agricultural pest is without question. Silverleaf whitefly has not been formally accepted as a common name by the Entomological Society of America's committee on common names of insects. However, repetitive use of the name within the scientific and agricultural community prompted the USDA Coordinating Group to adopt the silverleaf whitefly nomenclature at the 1994 progress review held in Orlando, Florida. The name will be retained throughout this document. The new plan encompasses studies on: (A) biology, ecology, and population dynamics; (B) viruses, epidemiology, and virus-vector interactions, (C) chemical control, biopesticides, resistance management, and application methods; (D) natural enemy ecology and biological control; (E) host plant resistance, physiological disorders, and host-plant interactions; and (F) integrated and areawide pest management approaches, and crop management systems. It also facilitates a coordinated technology transfer process and community-based partnership for implementation of areawide silverleaf whitefly IPM programs. The editors sincerely thank all those who participated in the development of this new research and technology transfer plan. We are particularly grateful to Dr. Dan Gerling, Tel Aviv University, Tel Aviv, Israel; Dr. Steve Naranjo, ARS, Western Cotton Research Laboratory, Phoenix, AZ; and Cindy Giorgio, University of California, Riverside, for their help and constructive comments in reviewing of the initial draft of this document.

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Acknowledgments:
The USDA Silverleaf Whitefly, Research, Education and Implementation Coordinating Group; Annual Review Program Chairs; Local and State Coordinators; SLW Program Planning and Review Committee; and the Silverleaf Whitefly Working Group sincerely appreciate the contributions of all the participants and those who have helped in organizing the meeting and developing the Silverleaf Whitefly 1997 Supplement to the 5-Year National Research and Action Plan: Progress Review, Technology Transfer and New Research and Action Plan (1997-2001).

Preface

The Silverleaf Whitefly (*Bemisia argentifolii* Bellows and Perring) Research, Action, and Technology Transfer Plan is an extension of the "5-Year National Research and Action Plan for Development of Management and Control Methodology for the Silverleaf Whitefly (formerly, sweetpotato whitefly, Strain B)" that was initiated in 1992 and terminates at the end of the 1996 calendar year. The duration of the new research, action and technology transfer plan is also expected to be 5 years. The silverleaf whitefly remains a serious national pest problem, resulting in estimated crop losses exceeding $500 million a year in the United States. The new plan defines the continuing need for a highly coordinated and cooperative program that includes the participation of federal and state agencies, universities and the agricultural industry. It also establishes new research needs, goals and objectives, and provides technology transfer to clientele (scientific community, legislators, regulators, the agricultural industry, and the public).

Progress in reaching goals and objectives will be reviewed on an annual basis. The new plan retains flexibility that will allow responsiveness to changing needs and priorities. As the SLW program continues to progress, participants will redefine essential activities and make appropriate adjustments to terminate, redirect, or add priorities based on funding, current knowledge, and program needs. The primary purpose of the plan is to provide focus for developing essential research and team efforts that will produce environmentally and socially acceptable, efficient and adoptable technologies for potential areawide, community-based silverleaf whitefly management.

This plan has been developed through the cooperative efforts of USDA agencies (ARS, APHIS, and CSREES), state agencies, state agricultural experimental stations, and the cotton, vegetable, ornamental, nursery crop and chemical industries. Our goals are to stress team research, address the highest priority research areas, avoid duplication of effort, and maximize the use of existing resources.

Important administrative responsibilities for the overall activity reside with the USDA Silverleaf Whitefly Research, Education, and Implementation Coordinating Group, and the Silverleaf Whitefly Working Group. The USDA Coordinating Group provides for coordination of USDA interagency activities and partner state agricultural experiment stations, and helps ensure a unified effort in support of the plan by assisting in annual progress reviews, identifying research and action priorities, and implementing technology transfer strategies. The Silverleaf Whitefly Working Group (previously Silverleaf Whitefly Technical Committee), composed of members from federal and state agencies, industry, universities, commodity groups, and other appropriate interest groups, meets annually and provides an information link to the USDA Coordinating Group. It also provides input to the Silverleaf Whitefly Program Planning and Review Committee, which schedules progress reviews, selects review locations, prepares reports, and helps guide the priority setting process.

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Executive Summary

The silverleaf whitefly 5-year national research and action plan has been a focal point for coordination; facilitation of cooperative research; and development of linkages among federal and state agencies, state agricultural experiment stations and commodity industries. A summary of research accomplishments and technology transfer for the terminating 5-year research and action plan, and a new research plan are described herein. The new research and technology transfer plan provides for continued research, methods development, education, extension, and technology transfer. Much of the research information gained to date has provided management tools to extension, education, and action agencies for use in silverleaf whitefly management programs. The new plan is expected to achieve the same or higher level of success as the original plan, with expanded participation from foreign countries as well as the United States. A proactive mechanism for technology transfer has been developed. Priority research and action areas have been revised to reflect our current knowledge of the silverleaf whitefly problem, provide for technology transfer to our clientele and develop areawide or community action programs. Annual reviews have been effective for information exchange, analyses, and identification of research needs, and will continue to be a vital part of the new plan.

Extensive research achievements, accomplished within the framework of the 5-year national research and action plan, have provided a better understanding of the silverleaf whitefly problem. A complete management system for silverleaf whitefly is a goal for the future, but at present, it is in the formative stages. Extensive fundamental, ecological, and biological research on the silverleaf whitefly and its natural enemies has revealed potential components for incorporation into an ecologically-based management system. Some crop management and community-oriented farm practices, such as water-use patterns, proximity of alternate host crops, and spatial considerations, are being implemented in an effort to provide overall silverleaf whitefly population reduction. Knowledge of the complex host interrelationships among cultivated crops, crop growing sequences, and urban community hosts has focused awareness that the farm community must concern itself with silverleaf whitefly population suppression programs. The new research and technology transfer plan identifies research and action activities to develop effective management methods and to increase our levels of technology transfer. Areawide, community-based approaches covering all commodities have emerged as having the best possible chance of success. Farmers must give careful consideration to all crops in the area, planting sequences, growth, and proximity to other crops. Crop production inputs also are important factors in silverleaf whitefly management for the numerous crops it attacks. The mechanisms involved in the complex interaction with the host plants and silverleaf whitefly population dynamics are largely unknown. These areas are high-priority focal points for investigation and clarification in the new research and technology transfer plan.

Although insecticides alone or in combination have been found to provide adequate control on major cultivated crops, insecticide resistance management is a particularly important factor that must be addressed. Other research and action areas of the plan reinforce the need for intensive development of biological and other nonchemical control, disease and silverleaf whitefly resistant plant types, and an expansion of our current knowledge of whitefly and natural enemy taxonomy, physiology, biochemistry, and genetics.

Table 1. Numbers of Research Reports[a] at the 1993, 1994, 1995, 1996, and 1997 Silverleaf Whitefly Annual Progress Reviews of the USDA 5-Year National Research and Action Plan.

	Research Priorities[b]						
Agency[c]/State	A	B	C	D	E	F	Total
1993 Review, Tempe, AZ							
APHIS	0	1	0	1	0	1	3
ARS	7	11	19	13	7	0	57
AZ	2	3	4	1	0	1	11
CA	3	3	4	2	3	0	15
FL	2	3	2	2	2	1	12
GA	0	0	4	0	2	0	6
NY	1	0	1	1	0	0	3
OH	0	0	1	1	0	0	2
TX	1	1	2	0	2	2	8
TOTAL 1993	16	22	37	21	16	5	117
1994 Review, Orlando, FL							
ADA	0	0	1	0	0	0	1
APHIS	0	0	0	3	0	0	3
ARS	7	14	13	10	5	1	50
AZ	7	4	5	4	2	3	25
CA	4	5	13	6	3	1	32
CDFA	0	0	0	2	0	0	2
FL	0	3	5	3	2	2	15
GA	0	0	1	0	0	0	1
HI	1	1	0	0	0	0	2
SC	0	1	0	0	0	0	1
TX	1	0	1	2	1	0	5
WI	0	2	0	0	0	0	2
OTHERS	1	0	4	2	0	0	7
TOTAL 1994	21	30	43	32	13	7	146

[a] From USDA 1993, 1994, 1995, 1996, 1997.

[b] A = Ecology, population dynamics and dispersal; B = Fundamental research, behavior, biochemistry, biotypes, morphology, physiology, systematics, virus diseases and vector interactions; C = Chemical control, biorationals and pesticide application technology; D = Biocontrol; E = Crop management systems and host plant resistance; F = Integrated techniques, approaches and philosophies; others (1994) = Dominican Republic, Valent, Miles, AirTech and Fermone Corps.

[c] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service; ADA = Arizona Department of Agriculture; CDFA = California Department of Food and Agriculture.

Table 1. (continued)

Agency[c]/State	Research Priorities[b] A	B	C	D	E	F	Total
1995 Review, San Diego, CA							
APHIS	1	1	0	6	0	0	8
ARS	4	4	19	12	4	0	43
AZ	8	5	5	1	0	2	21
CA	3	7	7	7	2	4	30
CDFA	0	0	0	2	0	0	2
FL	1	2	1	4	1	0	9
GA	0	0	1	0	0	0	1
HI	0	1	0	1	0	0	2
KY	0	0	0	0	1	0	1
NM	1	0	0	0	0	0	1
TX	1	0	2	1	1	1	6
WI	0	1	1	0	0	0	2
OTHERS	0	3	6	7	2	2	20
TOTAL 1995	19	24	42	41	11	9	146
1996 Review, San Antonio, TX							
APHIS	2	0	0	12	0	0	14
ARS	3	19	16	19	7	1	65
AZ	4	6	10	1	0	4	25
CA	3	2	12	1	0	0	18
CDFA	0	0	0	3	0	3	6
FL	0	1	2	5	5	1	14
GA	0	0	1	0	0	0	1
TX	0	3	0	1	2	0	6
OTHERS	0	0	6	8	1	1	16
TOTAL 1996	12	31	47	50	15	10	165

[a] From USDA 1993, 1994, 1995, 1996, 1997.

[b] A = Ecology, population dynamics and dispersal; B = Fundamental research--behavior, biochemistry, biotypes, morphology, physiology, systematics, virus diseases and vector interactions; C = Chemical control, biorationals and pesticide application technology; D = Biological control; E = Crop management systems and host plant resistance; F = Integrated techniques, approaches and philosophies; others (1995) = Antibes, Egypt, Israel, Mexico, AgrEvo, Mycotech, Troy Biosciences, Valent; others (1996) = Costa Rica, Dominican Republic, France, Israel, Mexico, AgrEvo, Cotton Inc., Meister Research, Mycotech.

[c] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service; ADA = Arizona Department of Agriculture; CDFA = California Department of Food and Agriculture.

Table 1. (continued)

Agency[c]/State	Research Priorities[b] A	B	C	D	E	F	Total
1997 Review, San Diego, CA							
APHIS	0	0	0	12	2	0	14
ARS	7	9	7	10	5	2	40
AZ	2	8	2	7	0	2	21
CA	3	7	7	2	1	1	21
CDFA	0	0	0	4	0	0	4
FL	2	0	3	5	1	1	12
GA	0	0	0	0	1	0	1
TX	0	1	1	1	0	0	3
OTHERS	1	0	4	2	1	1	9
TOTAL 1997	15	25	24	43	11	7	125

[a] From USDA 1993, 1994, 1995, 1996, 1997.

[b] A = Ecology, population dynamics and dispersal; B = Fundamental research--behavior, biochemistry, biotypes, morphology, physiology, systematics, virus diseases and vector interactions; C = Chemical control, biorationals and pesticide application technology; D = Biological control; E = Crop management systems and host plant resistance; F = Integrated techniques, approaches and philosophies; others (1997) = Costa Rica, India, Israel, Lone Star Growers, Mexico, Mycotech, and Nihon Nohyaku Co., Ltd.

[c] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service; CDFA = California Department of Food and Agriculture.

Introduction - Brief History of the Program and Current Status

In 1991 and 1992, USDA agencies, state agricultural experiment stations, and commodity-involved industries in a cooperative effort formulated a 5-Year National Research and Action Plan that focused on developing methodology for control and management of the sweetpotato whitefly, Strain B (= silverleaf whitefly). Six high priority research and action areas were established during a series of meetings in Atlanta, GA; Reno, NV; and Houston, TX.

The USDA Sweetpotato Whitefly Research, Education and Implementation Coordinating Group (two members from ARS, two members from APHIS, two members from CSREES, and one member from SAES) was formed in 1992 to coordinate the USDA interagency activities. The USDA coordinating group and partner state agricultural experiment stations help ensure a unified effort for the program, and provided for an annual review to exchange research information, plan cooperative work, and evaluate research progress.

The sweetpotato whitefly has been a worldwide economic pest for many years, but of little concern in the United States until the late 1970s when epidemic outbreaks began to occur at sporadic intervals. Outbreaks continued through the 1980s on an increasing number of cultivated and weed hosts.

The transition from sweetpotato to silverleaf whitefly-infested agricultural systems in Arizona, California, Texas, and Florida appears to have occurred during the mid-to late-1980s. Economic losses from silverleaf whitefly have involved cotton and a wide range of ornamentals, melons and vegetable crops. Conservative estimates suggest that in 1991 and 1992 losses in the agricultural communities exceeded $200 and $500 million, respectively. Crop yield losses attributable to silverleaf whitefly in the Imperial Valley, CA over a 4-year period (1991 to 1995) have been estimated to be about $100 million per year.

The success of the 5-Year National Research and Action Plan and the annual progress reviews from 1993 through 1997 has resulted from the combined efforts of participating federal and state agencies and the agricultural industries. The urgent need for short-term technologies and the groundwork for long-term management have been established. Losses in agricultural communities where the silverleaf whitefly is a factor in crop and horticultural production have not increased. Significant research progress has been made and a number of management tools adopted in crop production systems. More importantly, a substantial base of new knowledge on biology, physiology, biochemistry, morphology, genetics, and other related fundamental information on the silverleaf whitefly has been obtained. Long-term economically, socially, and environmentally acceptable management systems are being developed from this knowledge base.

Extension and education activities have played a vital role in implementation and communication of silverleaf whitefly research outcomes and management technology. Integration of spatial analysis, geographic information systems, communications networking, ecological modeling, and extension programs is continually improving our efforts to provide information and management strategies to producers. An excellent insecticide resistance management program developed in California has been implemented, with a weekly newsletter to the grower community that assesses the status of chemical control effort. It also provides information on the need to alternate insecticide chemistry types in chemical control tactics. A long-term goal of integrating resistance management, crop sequencing, host-free periods, and crop residue and weed destruction, SLW population and plant disease monitoring, biological control, cultural controls, and other management options emphasize the need for coordination and cooperation of researchers, extension, personnel, educators, growers, industry, and the agricultural and urban communities.

At the 1996 annual review of progress held in San Antonio, TX, Dr. R. M. Faust, National Program Leader for Field and Horticultural Entomology, ARS, National Program Staff, Beltsville, MD, circulated a questionnaire (Appendix B) regarding future activities of the National Research and Action Silverleaf Whitefly Program. Of 160 registered participants, 50 responded. Eighty-five percent of the responding individuals indicated that a sequel to the existing plan should be prepared to maintain continuity and a continuing high level of coordinated research and technology transfer. The results of the survey and the continuing whitefly problem prompted the development of a technology transfer and new research plan as part of this document.

I. Technology Transfer for USDA 5-Year National Research and Action Plan (1992-1996)

Editor's Comments

When the silverleaf whitefly (SLWF) spread across the United States from 1986 through 1992, it was perceived as one of the most formidable agricultural pests that entomologists had encountered in some time. The ability of this insect to utilize a wide range of agriculturally important hosts in a variety of environments contributed to the estimated $1 billion in damage it has caused since its introduction. On some crop plants, the SLWF develops such high densities that they withdraw a sufficient amount of plant sap to kill the plants. On other commodities, they excrete large amounts of honeydew, on which sooty mold fungus grows. This sticky fungal mess taints foliage, fruit and fiber, resulting in down-grading of product quality. Still with other crops, whiteflies transmit growth-limiting viruses which reduce yield. These "multi-damage consequences" of SLWF infestations present problems which, by their nature, require the involvement and interaction of individuals representing multiple disciplines and multiple private, state, and federal agencies in search of viable strategies useful to agricultural producers.

In 1992, scientists, growers, and administrators representing various disciplines and agencies developed a five-year national research and action plan with the objective of developing management and control methodologies for the SLWF. Over the course of the last five years, many novel strategies have been generated and employed for SLWF control. As successful technologies have been developed, they were immediately integrated into the "on-farm" arsenal used by producers and have had a profound effect on reducing the damage caused by SLWF in certain cropping situations. With many research results, this technology transfer is obvious and the grower as the end-user benefits immediately. Other research findings, equally important to the long-term management of SLWF, have benefits to other end-users. These may include information used by regulatory agencies to set policy and administrators to direct funding, as well as information used by researchers to further scientific inquiry. Too often these "products" are not recognized by the agricultural community as significant to the overall SLWF battle, yet they form the foundation upon which tomorrow's discoveries are based.

In the pages that follow, research results submitted by various investigators are presented in a "results-based reporting format". This means that each result is identified by the *activity* (what research was done to generate the result), the *impact* (what resulted from the research activity), and the *outcome* (what measurable difference did the impact make). The editor has taken considerable latitude with the submissions to make them conform to the results-based format. While care has been taken to conserve the original intent of each author, errors in fact are the sole responsibility of the editor.

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Summary of Technology Transfer

The summarization all research that has been done on the silverleaf whitefly is a difficult task. Invariably what one individual deems as extremely important may be viewed as routine by another. The following tables were compiled with no attempt to rank the importance of the technologies; all of the results are valuable and should be reported. The information used to compile these tables was submitted by researchers from across the country, who have been associated with the five-year national research and action plan from 1992-1997. The six subject areas defined in the plan serve as an outline to summarize these technological advances.

Ecology, Population Dynamics, and Dispersal

Research on the population dynamics of SLWF has resulted in several direct approaches which are being used. By studying whitefly growth on various crops throughout the year, scientists have developed crop rotation strategies which result in breaking the seasonal life cycle of this polyphagous pest. Understanding how whiteflies migrate and establish new populations in fields has resulted in sampling protocols for cotton and melons. These give growers the tools they need to decide when and where control strategies should be implemented. Another product is the development of computer simulation models which utilize data on whitefly immigration and parasite efficacy to estimate appropriate times for release of natural enemies.

Fundamental Research - Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions

Through the five years of the plan, researchers have learned much about the biology of SLWF. This knowledge has lead to several novel control tactics. For example, studies on whitefly flight behavior and attraction to yellow have led to a new whitefly trap which is being integrated into monitoring programs across the country. This trap is less disruptive of natural enemies than the previously used yellow sticky trap. Courtship and mating behavior, coupled with biochemical and molecular techniques, have been employed to sort out the identity of SLWF and show how it is related to other species within the *Bemisia* complex. Similarly, by studying the molecular components of whitefly-transmitted viruses, scientists are learning more about how these pathogens are acquired and transmitted from infected to healthy plants. Field research to determine how virus epidemics occur have resulted in the implementation of host-free periods, effectively breaking the disease cycle. Work on the diet and feeding physiology of whiteflies have enabled scientists to develope methods of raising the SLWF on an artificial diet. This provides a tremendous tool that allows further detailed study into how this insect interacts with the chemical components of its many hosts. Additionally, this artificial rearing technique is being used to produce natural enemies without the critical step of needing to grow plants to support the whiteflies. Other chemical studies have lead to a novel method of treating cotton which has been tainted by whitefly honeydew, using an enzyme that breaks down the specific sugars excreted by the SLWF. Still other work has lead to the development of chemicals which induce plants to build up their defense systems, enabling them to better resist whiteflies.

Chemical Control, Biorationals and Pesticide Application Technology

In the area of insecticide development (whether synthetic or naturally based), there is a large group of researchers involved in the synthesis, development, application methodology, field evaluation, and registration of several novel whitefly insecticides. Some of the newly acquired and registered materials include imidacloprid (marketed as Admire, Gaucho, Marathon, Merit and Pravado), buprofezin (marketed as Applaud), and pyriproxyfen (marketed as Knack). Studies also have shown that certain combinations of currently registered materials, such as fenpropathrin (Danitol) - acephate (Orthene) mixtures in cotton, provide substantial improvements over single material application. Another area is the development of insecticides that are based on natural products chemistry such as neem seed oil (marketed as Trilogy, Triact and Rose Defense) and extracts of *Nicotiana gossei,* a wild cousin of tobacco. A significant related technology is the design and implementation of integrated programs which prevents the rapid onset of insecticide resistance. Finally, researchers have adapted conventional equipment and designed new techniques for more precise and accurate application of materials.

Biological Control

There have been significant advances in the biological control of SLWF using predators, parasites, and pathogens, and commercial production of agents has resulted from scientific examination of these agents. Studies on the nutritional requirement of predators, like ladybird beetles and lacewings, have resulted in artificial diets which enhance the efficiency of rearing. These and other predators have been evaluated in field release trials, and mass rearing and release is now taking place in certain field and greenhouse situations. The use of parasites in biological control of SLWF has commanded a substantial amount of scientific study. Researchers have conducted regional surveys documenting the existing parasite fauna, which aids in determining which exotics may have the most impact on whiteflies in these regions. A tremendous search worldwide for exotic parasites has resulted in numerous populations (often of new species) being evaluated, mass reared, and released throughout the U.S.. These have significantly contributed to the natural mortality of SLWF. Research on pathogens which attack SLWF has enabled companies to culture and formulate large amounts of these important natural enemies which can be sprayed in field situations. Several fungal-based products are now available to be used by the grower. Finally, researchers have developed integrated programs which enable releases of natural control agents in concert with chemical insecticide applications.

Crop Management Systems and Host Plant Resistance

Exciting advances have been made in designing grower-implemented cultural control strategies for SLWF. For example, research has proven that growing high-value vegetables over reflective mulches slows development of whitefly populations. Work has shown that intercropping with whitefly suitable hosts using trap crops can effectively protect some commodities. Mixing plant communities around fields can serve to preserve and enhance biological control from predators and parasites. Manipulation of fertilizer rates, irrigation frequency and timing can alter plant growth so that they are less suitable for whitefly population development. In the area of host plant resistance scientists are making progress toward developing resistant varieties of various commodities, such as alfalfa and cotton, with release in the near future.

Integrated Techniques, Approaches, and Philosophies

The last area in the USDA plan is the science concerned with taking all information gained through research and integrating it into viable pest management programs. One of the advances over the past 5 years is the development of computer technology linked to satellite imaging which allows large area-wide mapping of crop types. Coupled with whitefly sampling techniques, these models can be used to design crop sequence patterns to the detriment of the SLWF. Scientists have organized community-wide task forces which have facilitated the delivery of information to the growers. Workshops have shown growers how to sample whiteflies and when to initiate control methods. Additionally researchers in some geographic areas provide information on the prevention of insecticide resistance. Scientific publications and various meetings facilitate communication among scientists, while numerous pamphlets and electronic media have been written and distributed to the grower community.

New Products

Like the biological organism which is the focus of the research reported herein, the development of products used to control SLWF is continually evolving. As such, there are several technologies submitted by researchers which are near completion and should be available in the near future. For example, Larry Heilmann (701) 239-1301, *heilmanl@fargo.ars.usda.gov*, has isolated several species-specific satellite DNA sequences from *Encarsia formosa* and *Eretmocerus mundus,* two parasitic wasps. In the near future, DNA sequences may be used to identify other wasps in the *Encarsia* and *Eretmocerus* genera. While presently these groups are difficult to tell apart, the technique created with the DNA sequences will facilitate rapid detection.

Steve Naranjo (602) 379-3524 x241, *snaranjo@asrr.arsusda.gov*, has conducted studies on the distribution of sticky cotton lint, allowing the optimization of sample unit size, and determination of the number of samples needed for the precise estimation of lint stickiness. These data will be used to formulate efficient sampling plans for sticky lint. The plans will lead to more efficiency in the use of enzyme sprays which have been developed to reduce stickiness in lint.

A third upcoming product was submitted by Michael E. Salvucci (601) 379-3524 x227, *msalvucc@asrr.arsusda.gov,* who has conducted laboratory experiments using an artificial diet to examined how whiteflies metabolize ingested plant sugar. These experiments revealed that the whitefly honeydew sugar, trehalulose, was synthesized for the excretion of excess carbon. The essential role of this sugar in whitefly metabolism suggests that inhibition of its synthesis would provide a means of controlling whiteflies. A potential product would be an inhibitor of trehalulose synthesis, which would cause metabolic and osmotic imbalance in the whitefly, leading to reduced viability. This would provide a novel type of strategy for control.

These examples give a flavor for the types of products that will be developed in the near future. Combined with the technologies that already are in the hands of end-users, one has an impressive view of the impact of scientific research. While the SLWF continues to plague growers of various commodities in certain geographic regions, the availability of new technologies has lessened its impact considerably. Only with continuing research and cooperation among the multi-disciplinary, multi-agency scientists will the silverleaf whitefly, a significant entomological threat to agriculture, be managed completely.

I. Technology Transfer for USDA 5-Year National Research & Action Plan (1992-1996)

ACTIVITY	IMPACT	OUTCOME
Sampling Scheme and Action Threshold for Whiteflies Helps Spring Melon Growers **Contact: David N. Byrne (520) 621-1151, e-mail: byrne@ag.arizona.edu**		
Over the course of three growing seasons a series of variance/mean statistical models were tested to determine how to best measure whitefly population levels in spring cantaloupes.	A method for accurately assessing whitefly densities was developed and coupled with yield loss information to develop a threshold for treatment.	Treatment guidelines were synthesized into a Cooperative Extension bulletin that provides growers with the ability to estimate whitefly numbers in their fields. This reduces unnecessary insecticide applications by basing sprays on whitefly counts.
To make appropriate decisions concerning pesticide applications, a reliable sampling scheme must be available. Our studies have shown that visual observations of adults on leaves provide an accurate and practical method for estimating field densities. We have developed a presence-absence sampling scheme which involves counting the number of leaves with one or more adult whiteflies (i.e., are they there [present] or not [absent]) and relating these to the mean number of whiteflies per leaf across the field. In experimental fields, when whitefly numbers reached 25 adults per leaf, the result was a yield reduction of 52%, a 2% loss in total sugars, and excessive stickiness on 50% of the fruit. Based on these data and the presence-absence scheme, three whiteflies per leaf is the action level for whiteflies on spring melons, and control measures should be taken when populations reach this level.		
Computer Simulation Model Useful for Managing Whitefly Populations in the Field and Greenhouses **Contact: Gloria DeGrandi-Hoffman (520) 670-6380 x105, e-mail: gdhoff@aol.com or Steve Naranjo (602) 379-3524 x241, e-mail: snaranjo@asrr.arsusda.gov**		
Data on whitefly migration and efficacy of parasites and predators were used to generate model.	Simulation model developed with plans to distribute as public domain.	New tool for researchers and growers which can estimate migration rates and guide decisions for timing releases of natural enemies.
A computer simulation model of whitefly parasite & predator population dynamics was constructed. The model will be distributed as public domain software for DOS systems. The program is useful for determining the potential efficacy of biocontrol agents (parasites & predators) for managing whitefly populations in the field and in greenhouses. The model can direct decisions for the timing of augmentative releases of parasites and predators.		

ACTIVITY	IMPACT	OUTCOME
Water Management in Cotton Reduces Whitefly Numbers **Contact: Hollis Flint (602) 379-3524 x230, e-mail: hflint@asrr.arsusda.gov**		
Water-stress found to affect whitefly population development.	Whitefly populations are reduced significantly when cotton plant water stress is avoided.	Information released through scientific, extension, and university publications and appears in extension recommendations.
Field studies were conducted for three years in Arizona on water management with drip and furrow irrigation to determine effects on whitefly population dynamics. Results of the research showed that avoiding plant water stress reduced whitefly population development. The results have been implemented in the grower community as a result of technology transfer accomplished through meetings, workshops, and university extension recommendations. Additionally, the findings have stimulated other research to determine effects of other cotton production methods in whitefly populations.		
Seasonal Dynamics of Silverleaf Whitefly in the San Joaquin Valley Give Scientists Clues for Management **Contact: Larry Godfrey (916) 752-0473, e-mail: ldgodfrey@ucdavis.edu**		
Surveys throughout the year identified host plants utilized by the silverleaf whitefly.	Research lead to a better understanding of the biology of the whitefly and which crops are impacted.	Seasonal dynamics are being formulated into cultural control strategies, crop sequencing, determination of susceptible points in the whitefly cycle.
The San Joaquin Valley of California is an extremely diverse agricultural area with 250+ crops as well as weed and ornamental plants. Many of these plants are whitefly hosts. This diversity, along with the cool, wet winters, provide a unique set of conditions to study the biology of silverleaf whitefly. The number of host plants, most favorable hosts, overwintering hosts, role of weeds, host sequence during the season, etc., were evaluated in this study. Information was relayed to clientele through newsletters, presentations, popular articles, and other viable means.		
Action Threshold Available for Management of Whiteflies in Cotton **Contact: Steve Naranjo (602) 379-3524 x241, e-mail: snaranjo@asrr.arsusda.gov or Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu**		
A multi-institutional cooperative project in Arizona, California, and Texas from 1994-1995 evaluated sampling methods and action thresholds for cotton.	A regional management program was developed incorporating new thresholds with existing sampling protocols.	Insecticide applications are optimized using new thresholds, thus enhancing the economic viability of cotton.
Field studies conducted in Arizona, California and Texas from 1994-1995 by a multi-institutional team led to the development of action thresholds for whiteflies infesting cotton. Action thresholds are an essential component of modern IPM and provide a means for growers and pest control advisors to make rational, economically-based decisions regarding the need for pest control. These thresholds have been integrated with existing sampling protocols and disseminated through extension circulars, grower training seminars, and commercial demonstrations. Use of these thresholds has enhanced the economic viability of cotton production by optimizing the timing and efficiency of insecticides used for whitefly suppression.		

ACTIVITY	IMPACT	OUTCOME
Sampling and Decision-Making Protocols for Adult Whiteflies in Cotton Transferred to the Farmer **Contact: Steve Naranjo (602) 379-3524 x241, e-mail: snaranjo@asrr.arsusda.gov**		
Developed sampling program for adult whiteflies in cotton and wrote protocols that are easy for the grower to understand.	Distributed 6,000 copies of sampling protocol. Conducted workshops and training programs in the field.	Protocols have reduced pesticide use, slowed pesticide resistance, and enhanced the economic viability of cotton.
Collaborative research between ARS and University of Arizona resulted in the development, validation, and implementation of fast and reliable methods of estimating whitefly abundance for the purpose of scheduling pest control actions in cotton. The protocols for adult and nymphal sampling have been disseminated through extension circulars (6,000 copies), grower training seminars, and demonstrations in commercial production fields. The protocols are being widely used in Arizona, California, and Mexico, and have been disseminated to other countries including Israel, Pakistan, and Australia. The protocols have reduced pesticide use, extended the longevity of existing insecticides by slowing the development of resistance, and enhanced the economic viability of cotton production.		
Sampling Method for Whiteflies in Cotton Aids Researchers **Contact: Steve Naranjo (602) 379-3524 x241, e-mail: snaranjo@asrr.arsusda.gov**		
Field research of sampling plans for all life stages of whiteflies on cotton was conducted.	Reliable and cost-efficient sampling methods were developed.	Techniques have been adopted as standard by researchers throughout the southern cotton belt of the U.S. Approach and methodologies serve as a model for developing sampling plans for whiteflies on other crops.
Field research led to the development of reliable and cost-efficient sampling methods and plans for estimating the density of all stages of whitefly in cotton. These techniques have been adopted as standard methodologies by researchers throughout the cotton belt for studies of population dynamics and development of economic thresholds. Further, the experimental approach and methods of analysis have served as a model for development of sampling plans for whitefly on other affected host crops.		

ACTIVITY	IMPACT	OUTCOME
Regional Surveys of Whitefly Host Plants Used by Local Grower Committee **Contact: Tom Perring (909) 787-4562, e-mail: thomas.perring@ucr.edu**		
Area-wide searches for whitefly reproductive hosts on crop and weed hosts were conducted throughout the year from 1992-1996	A comprehensive data set on seasonal whitefly cycle overlaid upon crop rotation and weed abundance was developed.	Data were used by the Imperial County Whitefly Management Committee to support requests from Federal and State sources for continued funding of whitefly research in southern California. Data also were instrumental in showing year to year comparisons for Section 18 registration of imidacloprid on melons.
In the 500,000 acre Imperial Valley of California, 5 regions which were 5 miles square were chosen for sampling. These regions represented the geographic and plant species diversity present in the Valley. Within each region, surveys of all plant species were conducted and every 2 weeks, samples of each plant were evaluated for the presence of whitefly nymphs. For each sampling, plant foliage was examined in the field for a total of 10 minutes, counting the number of 3rd and 4th instar whitefly nymphs. A subsample then was taken to the laboratory for microscopic evaluation of live, dead, or parasitized nymphs. These counts were used to transform field-collected data to provide an estimate of the plants which were contributing to the regional whitefly abundance. Data found that of 50 plant species sampled, relatively few were considered excellent whitefly hosts. Many plants became infected only when large numbers of whiteflies migrated from source fields. Surveys results were communicated to growers via the local press.		
DNA Sequence Database Provides Information on Whitefly Transmitted Geminiviruses **Contact: Judith K. Brown (520) 621-1402, e-mail: brown@biosci.arizona.edu**		
Molecular detection of whitefly-transmitted geminiviruses. DNA sequences of the 550 bp middle 'core' region of the coat protein (CP) gene from geminiviruses were developed.	Universal PCR primers have been designed to target the core CP region, permitting rapid detection, cloning, and sequencing of this marker, and detailed molecular comparisons between uncharacterized geminiviruses.	A database including the core sequences along with relevant biological data and key references facilitate identification of geminiviruses, worldwide.
The coat protein (CP) gene is being evaluated as a useful molecular marker for geminiviruses for several reasons. The CP is the most highly conserved gene among the Geminiviridae. This can be seen by alignment of CP gene sequences of geminiviruses characterized to date, and functional evidence surrounding the role of the CP corroborates the observed sequence conservation. Constraints imposed on the coat gene are thought to include requirements for strict virion capsid morphology, specific interactions between the capsid protein and the host plant, and capsid-vector specificity requirements with their insect vectors to achieve transmission. Our hypothesis is that these characteristics, collectively, make the gene particularly interesting and useful for making predictions about evolutionary relationships between geminiviruses. A database has been established in the Arizona laboratory that contains DNA sequences obtained from the middle 'core' region (550 bp) of the coat protein gene. Sequences are obtained by PCR amplification of this gene region using universal PCR primers that detect all whitefly-transmitted (WFT) (subgroup III) geminiviruses evaluated to date. Initial efforts have focused on archiving sequences for well-characterized geminiviruses, followed by addition of partially characterized isolates. By this analysis the CP gene is informative about virus vector, host, and recent geographic origin.		

ACTIVITY	IMPACT	OUTCOME
Development of New Adult Whitefly Trap Aids Whitefly Monitoring **Contact: C. C. Chu (619) 344-4184, e-mail: changchu@asrr.arsusda.gov**		
Studies throughout the U.S. have compared new adult traps to more traditional trapping methods.	Two new traps, which are reusable, not sticky, and not overloading can be used to monitor whitefly density changes over time. One trap is equipped with a small fan.	Provide additional tools to monitor whiteflies for research and management purposes. One of the trap types has been adopted by Agricultural Commissioner for regulatory use.
Yellow sticky card traps have been the only means for monitoring whitefly population changes for regulatory purpose or as an index of whitefly density during dispersal in or out of a specific crop planting. Following whitefly adult behavior studies, a whitefly adult trap (CC trap) that is reusable, not sticky, and not overloading was designed. Results in 1995 and 1996 showed that the CC trap is a potential substitute for yellow sticky cards for whitefly monitoring. The trap has been evaluated extensively in the United States as well as in several other countries. The Imperial County Agricultural Commissioner's Office in California has adopted it for regulatory whitefly monitoring in 1996. A similar trap equipped with a small fan is a second option for long-term adult whitefly monitoring.		
Artificial Rearing System for *Bemisia argentifolii* Facilitates Research and Parasite Production **Contact: E. Davidson (602) 965-7560, e-mail: e.davidson@asu.edu**		
Assessment of plastic feeding systems, membranes and dietary components.	Ability to rear whitefly immatures without the necessity of using plants. Provides a bioassay to evaluate ingested materials on whitefly development.	Larvae were reared from egg to fourth instar on artificial diet; several intoxicants were assayed; *Encarsia* parasitoids were reared on whitefly nymphs without the plant.
A feeding chamber and diet were developed for rearing *Bemisia argentifolii* from eggs to fourth instar nymph under aseptic conditions. The feeding apparatus consisted of a plastic diet chamber covered with stretched Parafilm that was held in place by another piece of plastic and binder clips. Surface-sterilized eggs were placed on the Parafilm and the chamber was incubated in a petri dish at 90-95% RH, 25-27°C and a photoperiod of 16:8 h. The most successful diet consisted of 5% yeast extract in 30% sucrose. Developmental times of 1^{st}, 2^{nd} and 3^{rd} instar nymphs were 4.6, 3.4 and 4.2 d respectively, which is comparable to development times on plants. Although whitefly nymphs can be reared on this diet to 4^{th} instar, complete development to the adult stage was not achieved. The utility of the feeding system was demonstrated in bioassay with Ivermectin. The parasitoid, *Encarsia* spp. was reared to adulthood on whitefly nymphs produced on the artificial feeding system.		

ACTIVITY	IMPACT	OUTCOME
Chemistry of Whitefly Honeydew Leads to Treatment of Sticky Cotton **Contact: Don Hendrix (602) 379-3524 x226, e-mail: dhendrix@asrr.arsusda.gov**		
Biochemical analysis of whitefly honeydew sugars was conducted.	Identification of the complex carbohydrates in honeydew resulted in the identified key sugars related to cotton stickiness.	A specific enzyme was developed to degrade sugars on cotton lint. The enzyme was patented in Europe and the U.S.
A long-term study of the sugar components of whitefly honeydew revealed two insect produced sugars. These were trehalulose and melezitose. Trehalulose constituted nearly half of honeydew sugar content and was shown in associated studies to be highly correlated to cotton thermodetector counts. In cooperative studies with a commercial company that produces and markets for the baking industry, an enzyme was developed that efficiently degrades all the sugars in honeydew and has high potential for treatment of sticky cotton to alleviate the problem.		
Silverleaf Syndrome on Squash Attributed to Silverleaf Whitefly Nymph Feeding **Contact: Kim Hoelmer (619) 344-7857, e-mail: khoelmer@quix.net**		
Studied various life stages of silverleaf whitefly and sweetpotato whitefly ("Biotype A") with regard to silverleaf production on squash.	Determined only nymphs of silverleaf whitefly cause symptom.	Resulted in a useful diagnostic indicator for the presence of silverleaf whitefly worldwide.
Research demonstrated that feeding by nymphal stages, but not adults, of the silverleaf whitefly (sweetpotato whitefly strain "B") was the cause of squash silverleaf, a once-puzzling disorder of squashes, and other plant growth disorders of ornamentals. The occurrence of silverleaf is now recognized worldwide as a useful indicator of the presence of the silverleaf whitefly. The powerful systemic nature of silverleaf and similar physiological disorders induced by whitefly feeding has helped stimulate new research on regulatory mechanisms of plant development.		
Whitefly-Transmitted Viruses in South Texas Have Been Identified and Controlled **Contact: Tom Isakeit (210) 968-5581, e-mail: t-isakeit@tamu.edu**		
Surveys, field trials, and educational programs were conducted.	Growers and others in the agricultural industry are aware of the problem and their options.	Growers have used the information to alter their practices.
Since 1993, the occurrence of whitefly-transmitted geminivirus diseases in south Texas have been documented (their identity was confirmed by Dr. Judith K. Brown, University of Arizona). Control measures for squash leaf curl virus on watermelon, including insecticide, plant resistance, and physical barriers were evaluated. The use of transplants appears to be the best management approach. This information was communicated to growers and others in the agricultural industry via meetings, newsletters, and mass media efforts. Growers are now aware of the problem and many have implemented recommended control approaches in their operations.		

ACTIVITY	IMPACT	OUTCOME
Elicitors of Plant Defense Mechanisms Help Reduce Insect Pest Populations **Contact: Richard Mayer (407) 897-7304, e-mail: rmayer@ix.netcom.com**		
Evaluated/tested various plant defense elicitors.	Identified elicitors that reduce whitefly populations.	New product will be marketed by Morse Enterprises in Miami, FL.
Evaluated candidate elicitors of plant defensive mechanisms in the laboratory and the field. Several of them when applied in mixtures with foliar nutrient supplements reduced pathogen and insect pest incidence. We assisted in helping with formulating a new product for Morse Enterprises in Miami, FL. Product is to be marketed this year. Have also worked with Ciba Geigy on their BTH product which shows great promise for reducing insect pest population through induction of plant defensive mechanism.		
Research Discovers Whiteflies Induce Pathogenesis-Related Proteins **Contact: Richard Mayer (407) 897-7304, e-mail: rmayer@ix.netcom.com**		
Plant biochemical studies were conducted.	Pathogenesis-related proteins were induced as a result of whitefly feeding. These proteins may be important in isolating the plant from competing insect species.	Provides researchers clues on whitefly-host plant relationship.
Studies discovered that whiteflies induce pathogenesis-related proteins as a result of feeding and that these proteins may be important in isolating the plant from competing insect species. Pathogenesis-related proteins may also be useful in controlling insect populations. Studies indicate that the use of elicitors in field crops can reduce some insect populations.		
Identification of New Whitefly Species Answers Puzzling Biological Questions **Contact: Tom Perring (909) 787-4562, e-mail: thomas.perring@ucr.edu**		
Crossing experiments, studies on intraspecific and interspecific mating behavior, analysis of allozyme frequency, PCR analysis of genomic DNA and morphological evaluation were conducted.	Data indicated that the new strain of whitefly is a distinct species, *Bemisia argentifolii*, from the whitefly which had existed previously in the United States.	Increased understanding of the phenomena (such as plant disorders, host range switches and changes in virus complexes) which accompanied the introduction of the new species. Provided an example of how modern and traditional techniques can be combined to address the broader concept of the species definition.
Bemisia argentifolii Bellows & Perring, n. sp. was described from material collected in California and Florida. This species has been referred to elsewhere as *Bemisia tabaci* strain B. The species was demonstrated to be distinct from *B. tabaci* by crossing experiments, studies on intraspecific and interspecific mating behavior, analysis of allozymic frequencies, PCR analysis of genomic DNA, and morphological evaluation.		

ACTIVITY	IMPACT	OUTCOME
Artificial Feeding of Whiteflies Provides Methods to Study Whitefly Digestion **Contact: Rosemarie C. Rosell (520) 621-1402, e-mail: rrosell@ag.arizona.edu**		
Adult and larval whiteflies were fed a variety of fluorescent markers.	Adult and larval whiteflies can ingest particles as large as bacteria and appear to have similar digestive physiologies.	Provides researchers tools with which to study whitefly feeding and digestion.
Artificial feeding of whiteflies allows researchers to study whitefly digestive physiology. Fluorescent-labeled materials spanning a range of sizes were fed to adult and larval whiteflies to investigate the size exclusion limits of the mouthparts and digestive tract. There appeared to be no selective or direct shunting of macromolecules ranging from 512 Da to 2 million Da in size, or for movement of molecules as large as 0.2 µm from the foregut into the hindgut. However, large diameter spheres were excluded from the digestive system, probably due to a size limitation of the stylet food canal. Adult and larval digestive systems appear to be morphologically and functionally similar.		
Whitefly Hemolymph Sampling Facilitates Whitefly-Geminivirus Interaction Research **Contact: Rosemarie C. Rosell (520) 621-1402, e-mail: rrosell@ag.arizona.edu and Judith K. Brown (520) 621-1402, e-mail: brown@biosci.arizona.edu**		
Methods of collecting and analyzing hemolymph from single adult whiteflies for the presence of virus DNA was devised.	Geminivirus crosses the digestive system of vector whiteflies enabling them to be efficient vectors of viral diseases. In contrast, the digestive system of nonvector whiteflies is an effective barrier against the passage of geminivirus.	New research tool for the study of virus transmission, whitefly reproductive physiology, and the role of hemolymph proteins in metamorphosis.
The best method for collecting hemolymph, without causing damage to the digestive system, was by removing the hindwing from the whitefly thorax which caused a drop of hemolymph to be released which could be collected by microaspiration. Polymerase chain reaction was used to detect geminivirus in individual *B. tabaci* (vector) and greenhouse (nonvector) whiteflies. Virus DNA was detectable in the hemolymph of viruliferous vector whiteflies. In contrast, viral DNA was not detectable in the hemolymph of individual nonvector whiteflies. These data suggest that the digestive system of the nonvector whitefly serves as an effective barrier to prevent the passage of geminivirus into the hemolymph. In the vector, however, the digestive system epithelia provide points of specificity, possibly receptors, that allow geminiviruses to traverse digestive cells.		

ACTIVITY	IMPACT	OUTCOME
Feeding Experiments Identify Role of Key Whitefly Honeydew Sugar **Contact: Michael E. Salvucci (602) 379-3524 x227, e-mail: msalvucc@asrr.arsusda.gov**		
Laboratory experiments using an artificial diet examined how whiteflies metabolize ingested plant sugar.	The role of trehalulose for excretion of excess carbon was documented.	Essential role of this sugar in whitefly biology was established.
Uptake and metabolism of sucrose by adult whiteflies were investigated on defined diets containing 3 to 30% sucrose. Above a dietary sucrose concentration of about 10%, a greater amount of the ingested carbon was excreted by the whiteflies than was retained, and the proportion that was excreted increased progressively with increasingly dietary sucrose concentration. Carbohydrate analysis showed that the composition of the honeydew changed from predominantly glucose and fructose at low dietary sucrose concentrations to predominantly trehalulose at high concentrations. The results indicate that trehalulose is synthesized for excretion when carbon input from sucrose is in excess of metabolic needs.		
Electronic Techniques are Developed for Studying Details of Adult Whitefly Feeding **Contact: Greg Walker (909) 787-5808, e-mail: walker@citrus.ucr.edu**		
Specific electronic waveforms recorded by an electronic feeding monitor have been correlated with several specific stylet penetration behaviors.	The electronic monitoring technique provides researchers a tool to study details of adult whitefly stylet penetration that are not accessible by any other technique.	The electronic monitoring technique is now being used to study whitefly host plant selection and transmission of plant viruses by whiteflies.
Specific electronic waveforms recorded by an electronic feeding monitor have been correlated with intercellular advancement of the stylets, partial stylet retraction, intracellular punctures by the stylets, and phloem sieve element contact and ingestion. Thus, all of these otherwise unobservable behaviors can be recorded and measured from adult whiteflies feeding on plants. The technique is currently being applied to discover the behaviors that lead to acceptance or rejection of a plant as a host, and the mechanisms of transmission of plant viruses by whiteflies.		
Improved Methods for Field Evaluation of Agents Against Whitefly Assist Researchers **Contact: David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
Methods were evaluated for application of materials for whitefly control to lower surfaces of cotton leaves.	Methods permitted true evaluation of agent and were not confounded by application method.	Provides researchers a tool which allows testing with the knowledge that the agent and not the application method is being evaluated.
Methods were devised to apply prospective control agents to the undersides of leaves of cotton so the agent was actually tested properly without the test being confounded by application inadequacies, namely poor coverage of leaf undersides. This required exploration of new technologies such as air-assisted and electrostatic spraying systems, and improvement of existing hydrostatic spray equipment.		

ACTIVITY	IMPACT	OUTCOME
Improvement of Existing Hydrostatic Spray Equipment Provides Better Coverage Against Whiteflies **Contact: David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
Conventional hydrostatic spray equipment was reconfigured and tested to maximize spray deposition on undersides of leaf surfaces.	Methods were devised that utilized conventional spray booms but allowed for increased pressures and gallonage to be applied to under leaf surfaces.	A boom system was devised to control whitefly, aphids, and mites by hydrostatic ground application for under $4,000.00 U S.
These studies determined that defoliation booms could be altered to support conventional hydraulic spray rigging with position and direction adjustable nozzles in multiple sets. When these were coupled with increased pressure and gallonage, effective coverage of all cotton leaf surfaces was achieved for the first time with conventional spray equipment. The system was simplified to make it acceptable to producers, yet retain its application efficacy.		
Large Plot and Grower Field Testing Leads to Insecticide Resistance Management (IRM) Program **Contact: David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
Large plot testing (5 acres) was conducted in 1994-6 and rotational application schemes were tested for several insecticide classes.	Resistance monitoring of pyrethroids in rotational schemes provided IRM data that was incorporated into University of Arizona recommendations.	Arizona cotton growers were presented IRM recommendations by University of Arizona that were based on factual information.
Rotational application schemes were developed that utilized biorational, pathogenic, and conventional agents that did not target beneficial arthropods. These schemes permitted natural increases or argumentative releases of beneficials prior to rapid increases of silverleaf whitefly and simultaneously helped prevent development of whitefly resistance. These strategies were researched, developed, and evaluated as actual farm production methods. Information was obtained on temporal and spatial sequencing and spacing of different crops to minimize dispersal of whiteflies among them and consolidated into overall integrated technologies useful for existing and new procedures for cost-effective and environmentally safe insect control.		
Insecticide Mixture Reduces Losses to Whiteflies in Desert Cotton Production **Contact: C. C. Chu (619) 344-4184, e-mail: changchu@asrr.arsusda.gov or David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
From 1990 - 1993, fenpropathrin-acephat mixtures were evaluated for whitefly control on cotton.	Data were used to register fenpropathrin and the mixture has been used as a control standard for insecticide evaluation.	New tool for cotton producers provided substantial financial return.
In 1990, cotton plants treated with fenpropathrin were green longer. By the end of 1992, studies concluded that a fenpropathrin-acephate mixture was the best insecticide combination among many tested for silverleaf whitefly control on cotton. Fenpropathrin-acephate mixture has proven highly effective and the mixture has been used as a standard to evaluate other compounds for the silverleaf whitefly control. Results with fenpropathrin were used by Valent to register the compound for silverleaf whitefly control. Fenpropathrin has been used to control silverleaf whiteflies on cotton in Texas and Arizona since 1993 and California since 1994. The benefit of this compound to the cotton growers has been extensive but no dollar assessment is available. It can be stated, however, that without the early selection of the fenpropathrin, some agricultural production might not have survived.		

ACTIVITY	IMPACT	OUTCOME
New Insecticide (Imidacloprid) Provides Substantial Whitefly Control **Contact: C. C. Chu (619) 344-4184, e-mail: changchu@asrr.arsusda.gov**		
Evaluated efficacy and application methods for Imidacloprid in vegetable production systems in the desert southwest.	Data on efficacy resulted in registration against whiteflies attacking vegetables.	Growers provided new tool which has become the most used component of a short-term whitefly management program, providing substantial financial return.
The outbreak of silverleaf whiteflies in 1991 prompted an extensive evaluation of insecticides that might provide an immediate relief to growers while an integrated long term management strategy could be developed. Based on the whiteflies underleaf habitat, researchers envisioned in the fall of 1991 that systemic insecticides would be the best candidates for whitefly control. By the end of 1991, studies had selected soil application of imidacloprid as a potential candidate for whitefly control on vegetables. Data from studies were used to obtain a Section 18 emergency use permit and subsequently registration of the insecticide. The positive financial impact of imidacloprid on vegetable production in the southwest and southeast U.S. has been substantial. At this date, imidacloprid remains the most used component for silverleaf whitefly control in vegetable production.		
Monitoring Program Suggests Strategies for Sustaining Efficacy of Imidacloprid **Contact: Tim Dennehy (520) 621-7124, e-mail: tdennehy@ag.arizona.edu**		
In 1995-1996, statewide monitoring in Arizona was done to establish whitefly susceptibility to imidacloprid.	Data showed differences in susceptibility from sample site to sample site and between years.	Variables related to the spatial dynamics of whiteflies, hosts, and cropping systems were shown important in susceptibility. Data suggest conditions which may sustain efficacy.
In 1996 Arizona statewide monitoring of resistance in *Bemisia* showed differences in susceptibility to imidacloprid. Comparison to 1995 results indicated differences between years at some locations. Results from a regional study highlight the importance of the spatial dynamics of whitefly, hosts, and cropping systems, and suggest conditions that may sustain the efficacy of imidacloprid.		

ACTIVITY	IMPACT	OUTCOME
Chemical Control Guidelines Assist Cotton Growers in Management Decisions **Contact: Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu**		
Chemical efficacy trials from 1992-1995 were conducted in cotton in the desert southwest.	Data identified key compounds (Ovasyn in 1992, Danitol in 1993, and Provado in 1995) as part of the whitefly arsenal. Recommendations were tabulated.	Over 3000 growers have received recommendations. Demand for information and rapid changes have resulted in the production of pocket-sized laminated chemical use guides.
The discovery of the efficacy of combinations of pyrethroids with organophosphates led to short term, but dramatic, success in whitefly control in 1993 and 1994. This information was used widely by growers in Arizona, the Imperial Valley of California and the Mexicali Valley of Mexico. Furthermore, this testing was key in the registration of several key whitefly control compounds: Ovasyn in 1992, Danitol in 1993, and Provado in 1995. Two new chemistries representing novel approaches to whitefly management, Applaud and Knack were also found to be effective against whiteflies and have become part of a diversifying arsenal available against this pest via a Section 18 initiated in Arizona in 1996. Chemical use recommendations were tabulated in guidelines published in 1994 which were distributed to over 3,000 clientele. The demand for this information and the rapid changes in whitefly control technology prompted the production of pocket-sized, laminated chemical use guides in 1995 and 1996 as part of overall IPM plans.		
Section 18 for Two Insect Growth Regulators Useful in IPM Against Whiteflies **Contact: Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu or David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
Collaborative efforts between Cotton Incorporated, Arizona Cotton Growers Association, USDA, and universities in Arizona, California, Florida, Texas and Israel generated data on efficacy of Knack and Applaud insecticides for whitefly control on cotton.	Section 18 (Emergency Use Registration) was granted by EPA for both insecticides on the same crop-insect complex, a precedent-setting action.	Training sessions on the use of these materials were conducted, a whitefly management plan was distributed (5000 copies) and a video tape was produced. In demonstrations, whitefly insecticide usage was reduced by 60%.
Since 1993, Cotton Incorporated, The Arizona Cotton Growers Association (ACGA), USDA-ARS, the Arizona Department of Agriculture (ADA), and the University of Arizona have annually produced cross-commodity whitefly management guidelines which have been mailed to growers statewide by commodity groups. In 1995, this process contributed to the development of an integrated resistance management plan which provide guidelines for use of registered insecticides within a two-stage program based on systematic sampling and use of thresholds. The 1995 whitefly management plan was summarized in a bulletin, and 5,000 copies of this bulletin were distributed. In 1996, the ACGA, ADA, industry, grower groups, university scientists, Cotton Incorporated, and others collaborated to develop a Section 18 proposal which included emergency registration of two insect growth regulators: Knack (pyriproxyfen) and Applaud (buprofezin). The Section 18 was drafted to allow only single use of each material, require training before a grower or pest control adviser could use the insecticide, and required a minimum interval between use of the two IGRs. The resulting Section 18, which called for the exemption of two insecticides for the same crop-insect complex, was granted by the EPA in a precedent-setting decision. In controlled, large-scale demonstrations of IGR use, whitefly insecticides were reduced by 60% compared to the previous year. Furthermore, where IGRs were deployed according to the recommended management practices, there was a 40% reduction in whitefly insecticides compared to conventional regimes.		

ACTIVITY	IMPACT	OUTCOME
Insecticide Resistance Monitoring Program Allows Grower to Form Effective Management Strategies **Contact: Nick Toscano (909) 787-5826, e-mail: ntoscano@ucrac1.ucr.edu**		
Yellow sticky cards treated with various grower-available insecticides were evaluated over the season in several crops to establish a resistance monitoring program.	Monitoring program shown to be highly effective in helping growers design future management schemes.	Information on levels of resistance to various insecticides were distributed to growers via newsletters, newspaper and Internet media. These data help growers choose insecticides for their fields.
A resistance monitoring technique using yellow sticky cards sprayed with grower available insecticides provided baseline data for a number of insecticides used for control of the silverleaf whitefly in California. Continuous monitoring of the whitefly populations for changes in tolerance to insecticides in large regions allowed growers and pest control advisors to form effective management strategies. The whitefly-insecticides information was communicated via newsletters, newspapers, and the Internet.		
Application of Whitefly Fungal Pathogen Through Irrigation System Successful for Greenhouse Use **Contact: David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
Application of *Paecilomyces fumosoroseus*, a whitefly pathogen through a misting irrigation system was evaluated on tomato and cucumber.	Coverage was good and up to 67% control was achieved in a humid greenhouse setting.	Provides greenhouse growers an inexpensive and cost-effective method to use an environmentally-friendly whitefly control strategy.
Blastospores of *Paecilomyces fumosoroseus*, a fungal pathogen of whiteflies, were applied in suspension through a misting system onto whitefly infested tomato and cucumber plants. Coverage was good and up to 67% control was achieved under high humidity conditions in a controlled greenhouse setting. The delivery system is simple in structure, cost effective and simple to use.		
Entomopathogenic Fungus (*Beauveria bassiana*) is Incorporated into IPM Program **Contact: David Akey (602) 379-3524 x245, e-mail: thenneb@asrr.arsusda.gov**		
The entomopathogenic fungus *Beauveria bassiana* as Naturalis-l® was evaluated for whitefly control on cotton using the pyrethroid Capture® and or Mustang® as efficacy standards.	The entomopathogenic fungus *Beauveria bassiana* as Naturalis-l® was as efficacious as pyrethroids for whitefly control in cotton in desert environments.	Integrated Pest Management was advanced because an entomopathogen fungus controlled whiteflies and is compatible with chemical control.
This work with entomopathogenic fungi against whitefly produced a practical, usable, and feasible, biocontrol method that merged biocontrol with chemical control. In this 2-year study, cotton yields and lint quality were equal to cotton protected by use of pyrethroids. The use of this fungus represents the first effective biocontrol agent in use in the arid Southwest (important because of doubts whether entomopathogenic fungi could work in arid environments) against the silverleaf whitefly. These studies are important because conventional chemical control is recognized as a short-term solution for control and biocontrol agents are urgently needed for effective Integrated Pest Management programs.		

ACTIVITY	IMPACT	OUTCOME
Exotic Natural Enemy Releases Add to Regional Biological Control **Contact: Tom Bellows (909) 787-5735, e-mail: tom.bellows@ucr.edu**		
Three parasitoid species were introduced into quarantine, reared, and released, one species per year, into the Imperial Valley of California.	One of these species has become firmly established in the Valley.	The number of natural enemies present has been increased, adding to the natural control of whiteflies.
Field surveys in 1992 and 1993 showed that only 3 parasitoid species were present in the Imperial Valley, a 500,000-acre irrigated area in southern California. In each of 1994, 1995, and 1996, 3 different exotic parasitoids were introduced and cleared through quarantine, mass reared and released into the Valley on a variety of plant species at various times of the year. In 1994-1995, we released 382,800 *Amitus bennetti*. We have recovered a total of 157 parasites over the course of our release program from 2 urban sites and 1 agricultural site. In 1995-1996, we released 75,000 individuals of a new species of *Encarsia* n. sp. Recoveries of 2nd generation parasitoids have been made at 20% of the release locations. Currently we are rearing and releasing *Encarsia lutea* from Israel.		
Demonstration of a Biological Control-Based, Year-Round IPM Program **Contact: Matthew Ciomperlik (210) 580-7301, e-mail: a348mciomper@attmail.com**		
Releases of selected natural enemies carefully timed with biorational and synthetic insecticide application was evaluated on a year round rotation of broccoli, fall cucumber, cantaloupe and cotton in Texas.	Established successful biological control-based IPM program.	Overall reduction of whitefly densities with net savings to growers on late season pesticide application, coupled with a more environmentally-friendly control approach.
Biological Control-based IPM of *Bemisia* has been demonstrated, on a year round rotation of broccoli, fall cucumbers, cantaloupe melons, and cotton, using parasitoids, predators, and pathogens. The BC-IPM methods being used include early season releases of selected species of exotic parasitoids combined with biorational insecticides. In fall cucumbers, early season releases of *Eretmocerus* spp. (Pakistan & Spain) at a rate of 23 thousand per acre combined with applications of *Beauveria bassiana* controlled *Bemisia* populations below economic injury levels. In broccoli and cotton, the same species and release rate of parasitoids provided season long control. In spring melons, parasitoid releases were combined with a single application of imidacloprid which controlled whitefly, indicating that a net savings for agricultural producers of several applications of late season pyrethroids may be avoided in spring melons.		

ACTIVITY	IMPACT	OUTCOME
Mass Rearing and Distribution of Whitefly Natural Enemies Leads to Enhanced Biological Control **Contact: Matthew Ciomperlik (210) 580-7301, e-mail: a348mciomper@attmail.com**		
From 1993-1996, laboratory and field cage rearing methods were evaluated.	Techniques were developed which maximized efficiency, increased production, and lowered cost of natural enemy production. This allowed wide distribution of beneficials throughout the U.S..	Over 28 million parasitoids and predators representing 44 species/populations of natural enemies were distributed to 33 state and federal cooperators.
Forty-four species/populations of natural enemies were reared for distribution to over 33 State and Federal cooperators. Laboratory and field rearing methods were developed which reliably produced over 28 million parasitoids and predators from 1993-96. Field cage insectary rearing methods increased production and substantially lowered the cost of parasitoids. As a result, greater numbers of parasitoids were available for field evaluation and establishment efforts.		
Artificial Diet Used to Rear Whitefly Predators **Contact: Allen Cohen (602) 379-3524 x239, e-mail: acohen@ix.netcom.com**		
Studies of nutritional requirement for rearing *Serangium parcesetosum* (a ladybird beetle) and *Chrysoperla carnea* (a lacewing) were conducted.	Artificial diet was developed for 2nd instar *S. parcesetosum* and for all immature stages of *C. carnea.*	Enables large scale, laboratory rearing of two whitefly predators.
An artificial diet for 2nd instar *Serangium parcesetosum* and for all larval stages of *Chrysoperla carnea* was developed, and ARS submitted a patent application (Aug. 19, 1996) for this diet. Producers such as Beneficial Insectary are currently testing the diet, and a licensing strategy is being developed for commercial production. The predators will be used against whiteflies and other insects.		
Importation and Quarantine Screening of Imported Natural Enemies Supports Nationwide Release Program **Contact: John Goolsby (210) 580-7301, e-mail: a348jgoolsby@attmail.com**		
Parasitoids and predators were imported from Argentina, Brazil, Cyprus, Egypt, Dominican Republic, India, Indonesia, Israel, Italy, Malaysia, Pakistan, the Philippines, Sicily, Spain, Taiwan, Thailand and the United Arab Emirates during 1993-1996 and screened through quarantine.	Forty-four species/populations were evaluated and cultured.	These populations formed basis of a nationwide release studies of exotic natural enemies.
Forty-four species/populations of *Eretmocerus* and *Encarsia* spp., and 2 coccinellids were imported and cultured from: Argentina, Brazil, Cyprus, Egypt, Dominican Republic, India, Indonesia, Israel, Italy, Malaysia, Pakistan, the Philippines, Sicily, Spain, Taiwan, Thailand, and the United Arab Emirates during 1993-96. Natural enemies were screened in quarantine on several economically important crop plants including: cantaloupe melons, broccoli, and cotton. This information was used by researchers across the U.S. to select parasitoids for field evaluation and release.		

ACTIVITY	IMPACT	OUTCOME
Immunological Technology Helps Identify Whitefly Predators **Contact: James Hagler (602) 379-3524 x248, e-mail: haglerj@primenet.com**		
Over the past 5 years studies on predator gut content, using immunology, have been evaluated.	Developed monoclonal antibody which is specific to whitefly egg stage.	The antibody provides a tool for researchers interested in identifying which predators are feeding on whitefly eggs. Also, the indigenous predator complex in Arizona cotton fields have been elucidated using this technology.
Over the past five years, researchers have developed several predator gut content immunoassays employing a monoclonal antibody specific to the egg stage of *Bemisia*. Studies have thoroughly examined the indigenous predator complex in Arizona cotton fields for *Bemisia* prey remains. Using gut content immunoassays, key whitefly predators have been identified in a timely and precise manner. Currently, a dozen researchers from five different countries are using this *Bemisia* monoclonal antibody to examine predator populations indigenous to their areas.		
Pre-Release Evaluations of Natural Enemies Results in Successful Augmentation Biological Control in Greenhouse **Contact: Kevin Heinz (409) 862-3408, e-mail: kmh0700@zeus.tamu.edu**		
Screen 16 natural enemies, develop mass-rearing programs, release rates, and techniques for greenhouses.	Delivery of implementable biological control to greenhouse poinsettia growers.	Suppressed *Bemisia argentifolii* populations infesting commercial poinsettias without the use of any insecticides.
Commercial greenhouse growers can achieve effective biological control by releasing one *Encarsia luteola*/plant/week and one *Delphastus pusillus* at the same rate if control from parasitoids falters. With this strategy, the crop is produced without the use of any insecticides. These studies also facilitated commercialization of *D. pusillus* for sale from insectaries (from university to commercial product). The work has been communicated to growers by publishing the results and techniques in two greenhouse grower-oriented magazines and one refereed scientific publication. As a result of the program, growers went from one commercial natural enemy: *Encarsia formosa* (England) to six commercial natural enemies: *E. formosa* (England), *E. formosa* (Beltsville), *Eretmocerus* nr. *californicus* (Arizona), *Delphastus pusillus*, *Beauveria bassiana* (Naturalis-2), and *Beauveria bassiana* (Mycotrol BotaniGard).		
Information on Indigenous Parasitoids Useful for Designing Future Release Programs in the Desert Southwest **Contact: Kim Hoelmer (619) 344-7857, e-mail: khoelmer@quix.net**		
Surveys of native parasitoids across various seasons and crops were conducted.	Data showed fewer parasitoids than present in other geographic regions of the U.S., the native species developed more slowly than several exotic species (in this case *Eretmocerus*) and natives are less effective on certain crops (crucifers in this study).	Using this information, programs for future release of exotic natural enemies were crafted and are being evaluated.
Surveys of native species found that fewer species occur in desert valleys of California and Arizona compared with other regions, that the native species develop more slowly than several exotic species and that natives are less effective against whiteflies on crucifers. All were found to be contributing reasons for ineffective parasitism in desert crops. With this information, programs designed to enhance natural enemy activity were formulated and now are being implemented.		

ACTIVITY	IMPACT	OUTCOME
Surveys Show Introduced Exotic Parasitoids are Established in Desert Southwest **Contact: Kim Hoelmer (619) 344-7857, e-mail: khoelmer@quix.net**		
Surveys over the season were conduced in 1995 and 1996.	Recoveries of species indicate they have successfully overwintered, reproduced in the field, and dispersed from release sites.	New natural enemies are now active in melons and crucifers, two systems which were essentially void of parasitoids prior to release programs.
Releases of non-native whitefly parasitoids originally collected in various foreign localities have been made in desert valleys during the past several years. Surveys have shown that several of these introduced species have successfully overwintered, reproduced in the field, and dispersed from release sites. Several of the introduced natural enemies are very active in crucifers and melons, key crops in which biological control needs to be more effective. These newly-established species should continue to increase in numbers and impact whitefly populations, helping growers reduce their reliance on more intensive management methods.		
Whitefly Destroyer (*Delphastus pusillus*) Developed for Commercial Use as a Whitefly Predator **Contact: Kim Hoelmer (619) 344-7857, e-mail: khoelmer@quix.net**		
Experiments were conducted to determine efficacy of beetle and compatibility of releases with other strategies to control whiteflies in greenhouses.	Data showed good compatibility with biorational insecticide.	Provided tool for greenhouse growers to use.
Biological studies of this predatory beetle resulted in its availability from commercial insectaries worldwide, for use primarily by producers of whitefly-infested crops in protected culture such as in greenhouses. Use of this predator has proven to be compatible with the use of parasitoids and with the use of commercial formulations of neem-seed oils (azadiractin-containing products). Its availability has increased the options available to growers for use of biorational pest-management methods.		
Production Methods Allow Rearing of Fungal Pathogen to Control Whiteflies **Contact: Mark Jackson (309) 681-6283, e-mail: jacksoma@mail.ncaur.usda.gov**		
Develop low-cost liquid culture fermentation processes for stable, effective propagules of the fungus *Paecilomyces fumosoroseus*.	A medium was developed for producing high concentrations of blastospores (1×10^9/ml) of *Paecilomyces fumosoroseus*.	Allows *P. fumosoroseus* blastospores to be evaluated for commercial control of silverleaf whiteflies.
Liquid culture fermentation methods were developed to produce high concentrations of desiccation-tolerant blastospores of the entomopathogenic fungus *Paecilomyces fumosoroseus* in very short fermentation times. These blastospores effectively infect and kill the silverleaf whitefly. A cooperative research and development agreement was developed and performed with Mycotech Corporation for evaluating the commercial potential of using liquid culture-produced blastospores for controlling silverleaf whitefly.		

ACTIVITY	IMPACT	OUTCOME
New Fungal-Based Insecticide Useful for Whitefly Control **Contact: Stefan Jaronski (406) 782-2386, e-mail: mycotech@buttenet.com or Stephen Wraight (607) 255-2459, e-mail: spw4@cornell.edu**		
Industry and USDA scientists collaborated in multi-year studies to evaluate *Beauveria bassiana* against whiteflies.	Effective immature control was demonstrated, material was registered, and new mycoinsecticide production facility was constructed.	Safe and cost-effective tool added to whitefly management arsenal.
Mycotech, USDA-ARS-SARL (Westlaco, TX), USDA-APHIS-PPQ-PMDC (Phoenix, AZ), and USDA-APHIS-PPQ-BCL (Mission, TX) collaborated in developing, field testing, and registering a *Beauveria bassiana*-based whitefly mycoinsecticide. USDA conducted multi-year field programs which demonstrated effective nymphal whitefly control. Mycotech obtained US EPA registration under the tradename Mycotrol. The product is safe and doesn't adversely affect whitefly natural enemies or bees. Mycotrol is cost competitive with chemical insecticides. It fits in a broad range of whitefly control strategies; in combination with chemical insecticides for resistance management or fast knockdown of adults, as a stand alone product or in IPM programs. Mycotech constructed a commercial *B. bassiana* production facility with annual capacity of 500,000 treatment acres.		
Foreign Exploration of Whitefly Natural Enemies Drives Biological Control Efforts and Facilitates Taxonomic Studies of Whiteflies and Parasitoids **Contact: Alan Kirk (33) 46-704-5600, e-mail: akirk@cirad.fr or Lerry Lacey (509) 454-4463, e-mail: llacey@yarl.gov**		
Since 1991, searches in 25 countries of Africa, South America, the Mediterranean area, the Indian subcontinent, and Southeast Asia have been conducted.	Over 100 shipments have been sent to quarantine in the U.S. and 24 cultures of the two most popular genera (*Encarsia* and *Eretmocerus*) are maintained.	These efforts were the first step in the national biological control release effort now underway. They also provided specimens for systematic work on whiteflies and their natural enemies.
More than 100 shipments of SLWF natural enemies were sent to the APHIS/PPQ Quarantine, Mission, TX. by European Biological Control Laboratory scientists. 25 countries in Africa, South America, Mediterranean, Indian sub-continent and SE Asia have been explored for SLWF natural enemies. 24 cultures (with 14 distinct DNA patterns) of *Encarsia* and *Eretmocerus* spp. are maintained in quarantine. Releases have been made in CA, AZ and TX, and evaluations are underway. In addition to parasitoids, hundreds of fungal pathogen isolates were collected. The taxonomy of SLWF and parasitoids has been facilitated by the new and diverse material collected.		
Whitefly Parasitoid from Spain More Effective Than Native Parasitoid **Contact: Alan Kirk (33) 46-704-5600, e-mail: akirk@cirad.fr**		
Evaluated an *Eretmocerus* species from Spain against a native *Eretmocerus* species in Texas in laboratory and field trials (melons and crucifers).	Exotic parasitoid parasitized more whiteflies than native strain. Additionally, it was more tolerant of some pesticides.	Provides justification for mass rearing and release of the exotic parasitoid from Spain.
An *Eretmocerus* sp. from Spain (Murcia) was evaluated in collaboration with scientists from APHIS/PPQ and ARS laboratories in TX. Evaluation in both the laboratory and lower Rio Grande Valley on cantaloupe melons, kale and broccoli showed that this parasitoid parasitized more *Bemisia argentifolii* than the native *Eretmocerus* spp. and most other exotic parasitoids tested. In addition evaluation showed that it was more tolerant of some pesticides that native *Eretmocerus* and *Encarsia* spp.		

ACTIVITY	IMPACT	OUTCOME
Whitefly Parasitoid Native to Field Situations is Effective Biological Tool for Use Against Whiteflies in Greenhouses **Contact: Oscar Minkenberg (520) 321-7714, e-mail: parasite@ccit.arizona.edu**		
Lab and greenhouse studies were conducted to show efficacy of a field strain of *Eretmocerus* sp. (Arizona).	Data indicate this strain is effective in greenhouse situations.	Four commercial insectaries are mass-rearing this beneficial species and its distribution has resulted in significant reductions in insecticide usage.
Laboratory and greenhouse studies have shown that the parasitic wasp, *Eretmocerus* sp. (Arizona), is an effective biological control agent against whiteflies on various greenhouse crops. Some growers have implemented this new biological control method into their biologically-based integrated pest management system since 1993. Four commercial insectaries are currently mass-rearing this beneficial insect. Effective use of *Eretmocerus* has resulted in significant reductions in insecticide applications.		
Importation of Parasites in Florida Improve Control of Silverleaf Whitefly **Contact: Ru Nguyen (352) 372-3505, e-mail: mcginnn@doacs.state.fl.us**		
From 1990-94, 15 parasite species were introduced into Florida.	Parasites were recovered from field sites several weeks after release.	Parasites suppressed whitefly densities in several locations and have spread into other areas.
Efforts to develop a satisfactory IPM solution to the problem were initiated in 1990 by the introduction of exotic parasites into Florida. From 1990-1994, 15 parasite species were introduced into the Biological Control Quarantine Laboratory, Division of Plant Industry (DPI), Gainesville, Florida. Seven of these parasites, including *Amitus bennetti* Viggiani and Evans, *Eretmocerus* sp. (G) from Guatemala, *Eretmocerus* sp. (S) from Sudan, *Eretmocerus* sp. (HK) from Hong Kong, *Encarsia* sp. (G) from Guatemala, *Encarsia* sp. (I) from India, and *Encarsia lutea* (Masi) from Israel were approved by DPI and USDA-APHIS for field release in Florida. Approximately 305,000 *A. bennetti*; 157,800 mixed *Encarsia* sp., and *Eretmocerus* sp. from Israel, Guatemala, India, and Sudan, and 480,000 *Eretmocerus* sp. (HK) from Hong Kong were released between 1990-1994. These parasites were recovered from the fields a few weeks after release. The parasites suppressed the population *B. argentifolii* in several locations and dispersed into sprayed areas where a large number of parasites were release.		
New Whitefly Parasitoids Established in Central California **Contact: Charles Pickett (916) 262-2053, e-mail: cpickett@smtp1.cdfa.ca.gov**		
Over the past 3 years, 40 parasite populations have been released in the agricultural regions of central California.	Three of the populations have been recovered and have persisted for 1-2 years.	Establishment of these exotic natural enemies add to overall parasitism in the region.
At least three of 40 different populations of exotic aphelinids have persisted for one to two years following releases in the greater Bakersfield, CA area. *Eretmocerus* nr. *mundus* collected from Spain, *Eretmocerus* sp. from Multan, Pakistan, and *Eretmocerus* collected in Padappai, India were recovered from either hibiscus or purple potatovine grown by homeowners. Because the current native parasites have such low parasitism rates on silverleaf whitefly in cotton in the southern San Joaquin Valley, these new exotics may play an important role in reducing region-wide population densities of this whitefly.		

ACTIVITY	IMPACT	OUTCOME
Pictorial Key Helps to Identify Whitefly Parasites **Contact: Charles Pickett (916) 262-2053, e-mail: cpickett@smtp1.cdfa.ca.gov**		
Color photos and line drawings of all North American parasites attacking *Bemisia* whiteflies were collected and organized.	Developed a picture key that aids in identifying whitefly parasites.	This educational brochure provides scientists and growers a means to identify whitefly parasites.
A simple to use key with color photos and line drawings was developed into a laminated brochure. The key will aid parasystematists and others working on the control of the *Bemisia tabaci* species complex. It provides a simple key that identifies all North American parasites attacking whiteflies to genus and the known members of *Eretmocerus* to species. Biologies of *Eretmocerus* sp., the most important group of natural enemies attacking *Bemisia* species, are also provided. Funding for development of this brochure came from the California Department of Food & Agriculture's Biological Control Program. Additional funding came from the Texas Agricultural Extension Service, USDA-APHIS National Biological Control Institute, and Beneficial Insectary.		
Natural Enemy Refugia are Used to Establish Exotic Natural Enemies **Contact: Bill Roltsch (619) 351-0324, e-mail: brawlepc@smtp1.cdfa.ca.gov**		
Numerous plant species were screened for their ability to provide habitat through the entire year for whitefly natural enemies.	A combination of okra, basil, eggplant, collard and roselle provide year-long habitat.	In addition to contributing to natural control in field situations, home gardeners have used the mix to assist in establishing new exotic natural enemies.
Numerous plant species were screened for their ability to provide viable habitat throughout the entire year for whitefly natural enemies. Being of particular importance during winter when whitefly prey are scarce, such plants provide a stable, pesticide free environment for establishing new exotic species of natural enemies as well as conserving established species. A combination of early-planted okra, basil, eggplant, collard and roselle provide year-long habitat for exotic natural enemies to produce successive generations. In addition to their use in field plots, these plant have been used by home gardeners to assist in the establishment of exotic natural enemies.		

ACTIVITY	IMPACT	OUTCOME
Surveys Show a High Degree of Biological Control of the Silverleaf Whitefly in Florida **Contact: David J. Schuster (941) 751-7636, e-mail: djs@gnv.ifas.ufl.edu**		
Host plants of the silverleaf whitefly were surveyed for parasites and predators of the whitefly and for mortality induced by the natural enemies.	At least 13 species of parasites and 24 species of predators induced up to 90% mortality of the whitefly in habitats not disturbed by applications of broad-spectrum insecticides.	Scouts were encouraged to sample weedy perimeters of fields for the presence of the silverleaf whitefly and its natural enemies before recommending weed control and growers were encouraged to apply insecticides with minimal impact on natural enemies for the control of whiteflies and other pests.
Immature lifestages of the silverleaf whitefly were sampled on crop and weed hosts throughout Florida and the Caribbean for parasites. Tomatoes that were not sprayed with broad-spectrum insecticides were sampled twice weekly for predators of the whitefly using a drop trap. At least 13 species of parasites were reared from whitefly infested foliage and at least 21 species of predators were observed in the field or laboratory to feed on various lifestages of the whitefly. An additional three species of predators were identified from non-tomato habitats using ELISA. Weeds on perimeters of commercial tomato fields and vegetable crops on an organic farm were periodically sampled to monitor whitefly mortality induced by natural enemies. Mortality of nymphal whiteflies due to parasitism and predation increased to 90% in the weedy field perimeters. Therefore, weeds may serve more as reservoirs of natural enemies than as reservoirs of the silverleaf whitefly. Parasitism of the whitefly in eggplant and tomato on an organic farm increased to about 80%, while densities of whitefly nymphs decreased 85% to nearly 100%. Thus, conservation of parasite species through the use of selective insecticides can contribute to important levels of whitefly mortality.		
Seasonal Inoculations of Exotic Parasitoids Improves Natural Control of Whiteflies in Melons in the Desert Southwest **Contact: Greg Simmons (619) 351-0532, e-mail: gsimmons@ivcmcv.sdsu.edu**		
Several strains of exotic *Eretmocerus* were mass reared and released during early season melon production.	Parasitism was effectively increased and a strategy was found to be compatible with the use of imidacloprid.	Provides tool for melon growers to be used in whitefly arsenal.
Early-season releases of several mass-reared exotic *Eretmocerus* effectively increase parasitism of whiteflies in spring melons. The parasitoid releases appear to be compatible with other existing pest- management practices such as the use of imidacloprid. The success of these studies demonstrates the feasibility of seasonal inoculations as biorational management options and promotes their eventual transfer to commercial insectaries and growers.		

ACTIVITY	IMPACT	OUTCOME
Information on Exotic Parasitoids Useful for Designing Future Whitefly Pest Management in the Greenhouse Industry **Contact: Michael T. Smith (601) 686-5289, e-mail: mtsmith@ag.gov**		
Two new strains of *Encarsia formosa*, one from Greece and one from Egypt, were evaluated for use under different temperature conditions.	Data showed that the Greece strain was optimally adapted to cooler temperatures (16°C-21°C), while the Egypt strain was optimally adapted to warmer temperatures (26°C-31°C).	Provides greenhouse growers a cost-effective and environment-friendly whitefly control strategy in both warmer and cooler production systems.
World-wide, *Encarsia formosa* is the most widely used commercial biological control agent for control of whiteflies in protected plant culture (greenhouses). However, the current commercial strain has been shown to have limitations where plants are grown under less than optimal conditions, i.e., cooler vegetable production systems. Commercial production and utilization of these two strains is envisioned.		
Use of New Adult Whitefly Trap Preserves Natural Enemies **Contact: Kim Hoelmer (619) 344-7857, e-mail: khoelmer@quix.net**		
A study in cotton compared the selectivity of the new CC whitefly trap and standard yellow sticky card traps to whitefly parasitoids.	The new CC cup traps attracted and trapped whitefly adults but did not trap whitefly parasitoids (*Eretmocerus sp.*), while large numbers of parasitoids were trapped by the yellow sticky cards.	The new CC traps do not reduce parasitoid populations. They should be especially useful in greenhouses where whitefly traps are often used in conjunction with releases of parasitoids.
Results of a study in cotton demonstrated that the new CC cup traps are highly selective for whitefly, trapping whitefly adults but not whitefly parasitoids. Adult *Eretmocerus* are attracted to standard yellow sticky cards and become trapped in the glue. Since yellow sticky cards are widely used for whitefly monitoring and management, the new traps should be valuable for preserving whitefly natural enemies, especially in greenhouses where whitefly traps are frequently used in conjunction with releases of parasitoids.		
Cantaloupe is Protected from Whiteflies with Row Covers **Contact: Eric Natwick (619) 352-9474, e-mail: etnatwick@ucdavis.edu**		
Melons were sown into V-trenches and covered with spun-bonded mesh and embossed plastic row cover.	Strategy effectively protected seedlings from infestations by whiteflies.	Growers have adopted technique as a method to protect seedling melons from silverleaf whitefly. With the registration of Admire the growers can protect melon crops after row covers are removed.
Melons were planted into a V-trench of ten inch depth and twelve inch width, at the top of the bed. The V-trench then was covered with a tight fitting row cover to exclude whitefly adults and other insects. The row covers were removed when the plants began to bloom. Admire then was side-dressed to provide whitefly control later followed by foliar insecticide treatments. This method has been used successfully to produce fall melons.		

ACTIVITY	IMPACT	OUTCOME
Modification of Alfalfa Irrigation Practices Reduce Silverleaf Whitefly Densities but Cost Growers **Contact: Eric Natwick (619) 352-9474, e-mail: etnatwick@ucdavis.edu**		
A project in Imperial Valley, CA in 1991 and 1992 evaluated the effects of summer drydown of 6-8 weeks in alfalfa on infestation levels of silverleaf whitefly.	Modified irrigation practices reduced silverleaf whitefly numbers but resulted in loss of income due to reduced stands and fewer cuttings.	Most growers in the Imperial Valley tried this strategy in 1992, but few have continued for economic reasons.
Approximately 70% of the 200,000 acres of alfalfa in the Imperial Valley of California had irrigation terminated for four to eight weeks during the summer of 1992. Whitefly populations were lower than the previous summer. Migration of whitefly adults into fall plantings of winter vegetables were lower in 1992 compared to the previous year. Cost savings for reduced crop production inputs (irrigation, pesticides, swathing, raking, bailing, and stacking) were not off set by the loss of income from one or two cuttings of summer hay due to an improved alfalfa hay market in 1993. Some growers also had stand thinning problems following summer irrigation termination of six to eight weeks.		
Reflective Mulch and Drip Irrigation Add to Whitefly Management in Melons **Contact: Eric Natwick (619) 352-9474, e-mail: etnatwick@ucdavis.edu**		
Silver reflective plastic mulches were placed over cantaloupe melon beds. Fields with white reflective plastic mulch and drip irrigation were compared with furrow irrigated cantaloupe fields without plastic mulch.	Reflective plastic mulch bed covers produced melon plants with fewer whitefly adults and nymphs. Plastic mulch and drip irrigation improved soil moisture distribution and retention leading to better plant vigor and more timely insecticide applications.	Some growers in California and Arizona and all melon growers in Zacapa, Guatemala are using reflective plastic bed covers and drip irrigation for improved whitefly control in melon crops.
White or silver plastic mulch used as a tight fitting mulch over beds reflects sunlight to the undersides of the melon leaves confusing whitefly adults which utilize light for orientation. The plastic mulch also improves plant health by allowing the use of soil fumigation treatments prior to planting for control of soil borne pathogens. Plastic mulch improves plant health by maintaining even levels of soil moisture in the bed preventing stress and allows feeder roots to utilize the entire bed, thereby providing the plants greater access to nutrients. Drip irrigation allows for continual maintenance of proper levels of soil moisture and continual feeding of the proper levels of plant nutrients optimizing conditions for plant health and rapid growth by reducing stress. Maintenance of plant health and reduction of stress are vital to the ability of a plant to resist or tolerate insect damage such as that inflicted by whitefly feeding.		

ACTIVITY	IMPACT	OUTCOME
Whiteflies are Controlled in Cauliflower Using a Trap Crop **Contact: Eric Natwick (619) 352-9474, e-mail: etnatwick@ucdavis.edu**		
A project in California and Arizona from 1992-1993 evaluated the use of melons interplanted with cauliflower as a trap crop for silverleaf whitefly control.	A management practice using seedling melon as a trap crop to protected seedling cauliflower from silverleaf whiteflies was implemented in Arizona and California.	This effective strategy was used until Admire was registered, which alleviated the need for the trap crop.
Open pollinated cantaloupe melons were planted as a trap crop between two seedlines of cauliflower. The trap crop and cauliflower were allowed to grow together until the time for normally scheduled cultivation for weed control and fertilization. The trap crop and cauliflower were sprayed with an insecticide to control whitefly adults that may have moved from the melon trap crop to the cauliflower when the melons were cultivated out of the beds along with weeds.		
Screening of Pima Cotton Shows Potential Source for Whitefly Resistance **Contact: Richard Percy (602) 379-4221, e-mail: rpercy@ag.arizona.edu**		
Developed methodology for screening cotton genotypes and used technique to search for whitefly resistance.	Found several potential sources of resistance.	The potential resistance sources are being subjected to further evaluation.
Research identified okra-leaf and glabrous leaf traits as resistance factors. The wild diploid species *Gossypium thurberi* was identified as possessing an unknown resistance mechanism. Studies now are looking for, or developing, glabrous traits in agronomically better genotypes. In addition, research is evaluating genotypes which have been introgressed with *G. thurberi*, as well as further evaluation of okra-leaf genotypes.		
Crop Sequencing and Tomato-Free Periods Effective for Managing Silverleaf Whitefly and Tomato Mottle Geminivirus **Contact: David J. Schuster (941) 751-7636, e-mail: djs@gnv.ifas.ufl.edu or Phil Stansly (941) 657-5221, e-mail: pas@icon.imok.ufl.edu**		
Area-wide monitoring for tomato mottle geminivirus and sampling of silverleaf whitefly was conducted. Plant host range for the tomato mottle geminivirus also was determined.	Research showed growers that whitefly adults migrated from old plantings of susceptible crops to adjacent weeds or plantings of new crops, and viruliferous whitefly adults arose primarily from tomato.	Growers separated new plantings of tomato from old plantings, temporally and spatially, and lengthened the summer and winter tomato-free periods. This resulted in dramatic reductions of whiteflies and virus on tomatoes, especially in the fall.
Silverleaf whitefly populations were sampled on crop and weed hosts throughout Manatee and Hillsborough Counties, FL, using yellow sticky traps for adults and leaf samples for immature lifestages. The incidence of tomato plants with symptoms of the whitefly-transmitted tomato mottle geminivirus was also monitored in tomato in the two county area. The most important reservoirs of whiteflies were found to be crop plants rather than weeds. Winter vegetables that bridged the fall and spring tomato crops included cabbage and potatoes. Cucurbit crops served as sources of migrating whiteflies for late infestations on both spring and fall tomato crops. New tomato plantings near older tomato plantings either spatially or temporally had a higher incidence of plants with symptoms of the virus. Tomato was found to be the only major reservoir of tomato mottle geminivirus. Greenhouse studies confirmed that tomato was the major host of the tomato mottle geminivirus.		

ACTIVITY	IMPACT	OUTCOME
UV-Reflective Plastic Soil Mulches Assist in Managing Silverleaf Whitefly and Tomato Mottle Geminivirus on Tomato **Contact: David J. Schuster (941) 751-7636, e-mail: djs@gnv.ifas.ufl.edu**		
UV-reflective mulches were compared with conventional white and black polyethylene soil mulches in small plot and on-farm experiments.	Tomato plants grown on UV-reflective mulches had fewer alighting whitefly adults and a lower incidence of symptoms of tomato mottle geminivirus infection relative to white and black plastic.	About 15% of the tomato acreage in Florida is now grown with the UV-reflective mulch instead of the conventional white and black plastic.
Tomatoes in Florida are grown on raised soil beds covered with either white or black plastic in the fall to reduce soil temperatures or black plastic in the spring to increase soil temperature. UV-reflective mulch was substituted for white or black mulches in small plot and on-farm experiments. As long as the UV-reflective mulches were not covered either with plant growth or with pesticidal residues, the number of silverleaf whitefly adults alighting on tomato plants growing on the mulch was reduced and the incidence of plants with symptoms of the whitefly-transmitted tomato mottle geminivirus was delayed relative to the white or black mulches. About 15% of the tomato acreage in Florida now is grown on commercially produced UV-reflective mulch.		
Computer-Assisted Technology is Applied to Regional Whitefly Management Programs **Contact: Jon Allen (352) 392-1901 x150, e-mail: jallen@gnv.ifas.ufl.edu**		
Landsat images of California and Texas have been used to construct crop maps in whitefly impacted areas.	Experimental crop systems which reduce whitefly damage can be developed with computer simulation.	New research tool for developing regional whitefly management strategies.
Methods for constructing crop maps from Landsat images of agricultural areas were developed. This has been done for key whitefly areas (San Joaquin, Imperial and Lower Rio Grande Valleys). The impact of this is that we can now design experimental crop systems by computer simulation which reduce the whitefly. New management on a regional scale will then be suggested to reduce whitefly abundance.		
Cotton Cultivars Selected for Whitefly Resistance Reduce Insecticide Application in the Desert Southwest **Contact: C. C. Chu (619) 344-4184, e-mail: changchu@asrr.arsusda.gov**		
Studies from 1994-1996 evaluated whitefly susceptibility and yield.	Deltapine cultivars were less susceptible than Stoneville cultivars. DPL50, 5415, and 5461 required fewer insecticide application.	Growers can select less susceptible cotton cultivars and reduce damage by whiteflies.
Cotton cultivars have different susceptibility to whitefly colonization. Studies since 1994 in the Southwest demonstrated that Deltapine cultivars in general were less susceptible to whitefly colonization than Stoneville cultivars. Among Deltapine cultivars, DPL 50, 5415, and 5461 required fewer insecticide applications while achieving the same level of lint yield as the Stoneville 474 or LA 887. Cotton growers can reduce insecticide use by simply choosing less susceptible cultivars and using established treatment thresholds for silverleaf whitefly control.		

ACTIVITY	IMPACT	OUTCOME
Community-Wide Task Force Facilitates Regional Whitefly IPM **Contact: Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu**		
From 1993 to present, Univ. of Arizona extension personnel collaborated with local growers and pest control advisors representing 128 square miles of agricultural production.	A task force was formed which coordinated research activities and fostered educational communication and ultimately a pest control district (which hired a manager) was established.	Over 20 newsletters have been written and distributed to the community, sampling strategies were demonstrated on 8000 acres of cotton in 1994 and 14,000 acres in 1995. In one area pesticide applications were reduced from 12 applications in 1995 to as little as one in 1996.
A pest management task force consisting of University of Arizona extension personnel and local growers and pest control advisors (PCAs) was formed in the Laveen-Tolleson community of central Arizona in 1993. This program led to better cooperation and coordination of pest management activities among growers in this 128 square mile area west of Phoenix. From 1993 through 1995, regular meetings were held with growers, PCAs and program personnel, whitefly management practices were reviewed and community action was planned and implemented. Written works targeted group communication, education and information update and included over 20 newsletters, community data updates, bulletins and fact sheets. In 1994 whitefly sampling procedures were implemented and demonstrated in 8,000 acres of cotton. In 1995, growers formed their own pest control district targeting whiteflies and other pests and hired a manager and other personnel to sample whiteflies and coordinate pest management activities in over 14,000 acres of cotton. In 1996, cotton fields were treated based on recommended thresholds; a recommended integrated resistance management plan was used, and whitefly numbers were successfully managed with as little as one insecticide application (in 1995 up to 12 were required).		
Dissemination of Sampling and Threshold Protocols for Nymphal Whiteflies in Cotton Educate Growers **Contact: Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu**		
Develop methods of presenting data on whitefly nymph sampling and thresholds in an easily understood method for grower clientele.	A document was created and distributed. "Sampling Whitefly Nymphs" was distributed to 3,000 cotton growers.	Research information was extended to growers and incorporated in their whitefly management programs.
Sampling models developed by USDA-ARS and University of Arizona scientists were adapted for use by growers and pest control advisors (PCAs) and provide the basis for the University of Arizona Cooperative Extension Publication: IPM Series Number 6, Sampling Sweetpotato Whitefly Nymphs in Cotton. This protocol outlines decision-making plans needed for use of the changing whitefly management technologies available in Arizona, specifically, the two insect growth regulators (IGRs) Applaud and Knack. These sampling plans were introduced to over 700 growers and PCAs in six training sessions held throughout Arizona. In addition, 2 field workshops were held. Three thousand copies of the extension publication were distributed in Arizona, California and northern Mexico. Plans are underway to translate this publication into Spanish. Sampling and decision-making protocols were widely used in Arizona and facilitated the successful incorporation of the two IGRs into whitefly management practices in Arizona cotton.		

ACTIVITY	IMPACT	OUTCOME
Extension Resistance Laboratory Helps Growers Fight Whitefly Resistance **Contact: Peter Ellsworth (510) 568-2273, e-mail: peterell@ag.arizona.edu**		
Statewide surveys and studies on ecology and dynamics of resistance in whiteflies were conducted.	Data were produced that supported emergency registration of IGRs.	50% reduction in number of insecticides from 1995 to 1996.
With establishment of the University of Arizona Extension Arthropod Resistance Management Laboratory (EARML), Arizona producers no longer have to guess about the status of resistance in key insect pests. EARML activities involving whiteflies include statewide surveys, research into the ecology and dynamics of resistance of major whitefly insecticides and evaluation of resistance management strategies. Impacts and outcomes of the laboratory include producing the data supporting the recent emergency registration of IGRs, which in-turn contributed to an over 50% reduction in the number of insecticide applications made against whiteflies from 1995 to 1996.		
World-Wide Web Homepage Contains Information on Whiteflies **Contact: James Hagler (602) 379-3524 x248, e-mail: haglerj@primenet.com**		
Consolidated information on whitefly sampling, predators, research methods and bibliography of whiteflies and other cotton pests.	Developed a web page at http:\\gears.tucson.ars.ag.gov.wcrl which has received the highest rating by the WWW review service.	Researchers and growers throughout the world have instant access to updated research activities and information on whiteflies.
The homepage is designed to give people a glimpse of the research being conducted at the Western Cotton Research Laboratory. The homepage is not only targeted for researchers, but for the general public. This media gives browsers throughout the world instant access to the research activities of the United States Department of Agriculture, Agricultural Research Service. Recently this homepage received a 4 star rating (the highest given) by the independent WWW homepage review service, Excite Reviews. The homepage can be viewed on the WWW at http://gears.tucson.ars.ag.gov/wcrl.		
Bibliography of *Bemisia* Whiteflies Serves as Valuable Resource for Scientific and Lay Community **Contact: Steve Naranjo (602) 379-3524 x241, e-mail: snaranjo@asrr.arsusda.gov**		
Since 1992 the bibliographical data base of *Bemisia* has been updated.	Up-to-date reference source created. Also exists on the World Wide Web at: http://gears.tucson.ars.ag.gov/wcrl	Provides an easily accessible, current resource on all aspects of *Bemisia*.
Since 1992 researchers have been cataloging the world literature on *Bemisia* as an aid to scientists, educators, extension personnel, agricultural producers, industry, and governmental administrators. Since 1995 the bibliography and yearly updates have been published in the 5 year review document produced after the annual meeting each year. The bibliography and updates are also available electronically via the internet at http://gears.tucson.ars.ag.gov/wcrl. The bibliography can be downloaded in text, wordprocessor or Procite database format. Additionally, in collaboration with USDA-CSREES the database are offered along with Procite runtime software which enables users to search and print the database on their own computer.		

ACTIVITY	IMPACT	OUTCOME
Sticky Cotton Action Team (SCAT) Coordinates Interaction Between the Cotton Industry and Research Community **Contact: Robert L. Nichols (919) 782-6330, e-mail: 74103.2251@compuserve.com**		
SCAT was organized by Arizona producers with the guidance and support of Cotton Incorporated. Three or more planning meetings have been organized and funded annually since 1991.	SCAT has provided a forum for communication between the cotton industry and researchers, as well as among researchers from separate universities and agencies, including USDA.	SCAT published whitefly management plans for Arizona in the years 1993-1996 and for California in 1994 and 1995. From 1991 through 1996, Cotton Incorporated and its State Support Committees provided state universities and USDA with approximately $1.9 million for research.
SCAT is a model for joint action through partnership between an agricultural industry and the technical community. SCAT has provided a focus for situation analysis, rapid response, and research planning. Monies made available through Cotton Incorporated and its State Support Committees have leveraged several multi-agency regional projects that were beyond the financial resources of any single agency. SCAT provided a common ground for growers, ginners, and marketers to address needs and potential technical solutions. Agencies that have cooperated in development of publications sponsored by SCAT include Arizona Cotton Growers Association, Arizona Cotton Research and Protection Council, Arizona Department of Agriculture, California Cotton Growers Association, California Cotton Ginners Association, Calcot Ltd., Cotton Incorporated, Insecticide Resistance Action Committee (IRAC), Southwest Whitefly Resistance Management Working Group, United States Department of Agriculture, University of Arizona and the University of California.		
Computer Model Helps Evaluate Plant Resistance to Whiteflies **Contact: W. A. van Giessen (803) 556-0840, e-mail: wilant@aol.com**		
A number of life history parameters were evaluated and tied together in a way which makes it possible to express antibiotic resistance levels with just one parameter.	SARAH (Software for the Assessment of Antibiotic Resistance to Aleyrodidae in Host Plants), a simulation model of whitefly population growth on putative resistant germplasm, was written and tested.	The simulation model serves as a tool to combine life history components to obtain a single criterion for resistance. This method improves efficiency in breeding programs.
A deterministic computer simulation model (SARAH) was designed, incorporating life history parameters that can be measured relatively easily on individual host plants through the use of clip-on leaf cages. Parameters calculated were oviposition rate, pre-adult survival, adult survival, developmental period, adult longevity, maturation period, and sex ratio. SARAH was used to study plant resistance levels of the greenhouse whitefly on tomato and the sweetpotato whitefly on tomato, eggplant, collards, and peppers.		

ACTIVITY	IMPACT	OUTCOME
Computer Program Helps Scientists Study Whitefly Feeding Behavior **W. A. van Giessen (803) 556-0840, e-mail: wilant@aol.com**		
Raw waveform data from an Electronic Insect Feeding Monitor was converted into an easy-to-analyze format. Data files of various formats were imported into a custom-designed workbook and quickly analyzed. Results were summarized and output in a form which can be used by other statistical software.	A Microsoft Excel workbook was designed to analyze recordings of electronically monitored homopteran feeding behavior.	The workbook has proven to be a huge time-saver and is being used by researchers throughout the U.S. to study whiteflies and other homopteran insects.
An efficient method for the analysis of insect feeding monitor recordings was designed using Microsoft Excel, a popular spreadsheet software. After experimental details are entered and the data file is imported, a complete analysis is performed automatically. Results are summarized and an output file is generated for further statistical analysis. Any data file containing waveform codes and cumulative time can be analyzed. Use of the electronic feeding monitor workbook has the following advantages: (1) it can be used to analyze recordings of any homopteran species; (2) it is compatible with data acquisition software capable of exporting waveform codes and cumulative time, and with data files with a similar format; (3) it can be used in conjunction with both AC and DC systems; and (4) it is fast.		

II. Five-Year Plan Section Retrospectives (1992-96)

Section A. Ecology, Population Dynamics, and Dispersal

Compiled by Larry Godfrey*

An understanding of the biology of the silverleaf whitefly, *Bemisia argentifolii*, is critical for designing efficient management schemes. The ecology and dispersal characteristics of the target pest influences management through chemical, biological, cultural, and host plant resistance means. Therefore considerable effort was extended to define the life history, voltinism, population growth, overwintering, and dispersal of the silverleaf whitefly (SLWF). These data were used to drive population models, including population growth models and models of area-wide population distribution/levels. In addition, sampling plans and thresholds on key crops, based on a knowledge of whitefly biology, were developed. As more intricate management schemes are needed, additional, more detailed studies of SLWF ecology, population dynamics and dispersal are needed.

Several hundred plant species have been reported to be hosts for the silverleaf whitefly. However, some of these plant hosts may not be a reproducing host for this SLWF as whitefly adults may feed and oviposit on some plants but a complete generation not develop. Generalized cultivated host crop, urban planting, and weed plant host sequences supporting whitefly populations from spring through winter have been identified in Florida, Texas, South Carolina, Arizona, Imperial Valley of California, and San Joaquin Valley of California. This information may be useful for modifying the crop environment to manage SLWF. The overwintering site of silverleaf whiteflies, perhaps a susceptible point in their phenology, was of particular interest. Host plant sequences of whiteflies differed by state. In Florida, surveys indicated that winter/spring cabbage and potato crops may provide a reservoir for subsequent invasion into spring tomatoes. Fall-planted cucurbits, which had high densities of SLWF, were thought to be a source of infestations into fall tomatoes. Weeds appeared to contribute few SLWF to crops. In a mixed crop farm, SLWF densities varied with populations on tomato > eggplant > cucumber = zucchini > pepper. In the Texas Rio Grande Valley, cabbage harbored significant populations from December to April followed by spring melons. High densities in cotton were associated with high SLWF densities in nearby spring vegetable fields. SLWF overwintered on wild radish and in greenhouses in South Carolina. In the southwest, key hosts in Arizona were broccoli, cauliflower, lettuce, *Malva* spp. weeds, and urban plants (*Hibiscus*, *Lantana*, *Vinca*, roses, etc.) during the late fall/winter, spring melons, spring vegetables, and various weeds during the late winter/spring, and melons and cotton during the late spring/summer. Within Phoenix, about 50 species of landscape plants had moderate to high SLWF infestations. In California Imperial Valley, a cultivated plant host sequence pattern of cucurbits to cotton to alfalfa from the spring to late-fall was found. Several weeds species were also important. SLWF was identified from over 30 crop and 60 weed hosts in the San Joaquin Valley (California). The generalized host sequence (spring to winter) was spring melons, acala cotton, pima cotton, fall melons, weeds, cole crops, and citrus.

Laboratory host preference studies were conducted in several areas. Among the more important findings were that there was a positive correlation between SLWF oviposition magnitude and nymphal survivorship and a negative relationship between SLWF oviposition magnitude and developmental times. SLWF laid proportionally more eggs and survived better on zucchini than on cabbage or sugar beets. In a corresponding study, SLWF immature survival was highest on eggplant and lowest on garden beans. Intermediate values were found on tomato, sweet potato, and cucumber. The intrinsic rate of increase (r) recorded was 0.192. On cantaloupe, r values averaged 0.228 over a 24-day mating and oviposition period. The numbers of female progeny consistently exceeded that of males, >2:1 ratio on some days, during much of the emergence period (ratios were about equal on the other days). The highest number of progeny produced per female was 608.

Partial life tables were constructed on SLWF cohorts from field plots exposed to conventional or insect growth regulator insecticides. From a limited data set, predator-induced mortality greatly exceeded that from parasites. In one case, weather-induced effects (severe wind and rain) appeared to exert a significant detrimental effect on SLWF populations (~30% nymphal mortality).

Several agronomic factors were found to influence SLWF population dynamics on cotton. Phosphorus deficiency was found to reduce oviposition on young cotton leaves. Similarly, egg and nymphal densities were reduced by weekly, compared with biweekly, irrigation and on plants with blooms manually removed compared with plants with a normal complement of blooms. The reductions in egg and nymph numbers resulted because of a lower density of adults on leaves of these treatments.

SLWF sampling plans have been developed for cotton and cantaloupes and provide a basis for growers, pest control operators and researchers in development and implementation of action thresholds. Sampling studies have also been conducted in tomatoes and greenhouse poinsettias. Direct counts of adults (and immatures) generally provided more robust and reliable estimates of densities then indirect sampling methods. Indirect methods tested included sticky traps (cylindrical and round), hand-vac, and suction traps. Sequential and binomial sampling plans were refined and implemented on cotton and melons. On cotton, sampling the fifth main

stem node leaf produced the most reliable estimates of SLWF nymphal density; egg densities were greatest on the youngest leaves. In cantaloupes, adult and nymphal SLWF were more abundant on terminal leaves whereas the eggs were more abundant on crown leaves. Bionomial sampling plans for cotton and melons, to allow for ease in classifying damaging levels of SLWF, were implemented in IPM programs in the United States and internationally. The cotton sampling plan was validated in more than 8000 acres of commercial production. Plans are re-evaluated and refined frequently as intervention strategies change. The use of insect growth regulator insecticides in Arizona cotton in 1996 required a modification of the existing sampling plan. Sampling plans on other crops are also being developed. For instance, on tomatoes, distributions of SLWF lifestages depended on leaf age, i.e., eggs, nymphs, and pupae were most abundant and variation lowest on leaves at nodes 4-6, 6-8, and 8-10, respectively.

Field sampling methods for estimating cotton lint stickiness are being developed. Lint stickiness appears to be uniformly to randomly distributed in a cotton field as contrasted to the highly clumped SLWF distribution. Research to optimize sampling resources and to increase relative precision are underway.

The relationship between SLWF densities and yield of cotton and cantaloupe , as well as cotton lint stickiness, has been studied. Yield thresholds are fairly well established but need to be continually refined in response to available management strategies. Action threshold studies on cotton were conducted in Texas, Arizona (Yuma and Maricopa) ,and California (Brawley and Bakersfield). A simple economic analysis showed that the net return was highest for a action threshold of 5-10 SLWF adults per leaf. As another measure of plant response to SLWF . feeding, cotton photosynthetic rates were examined. Photosynthetic rates of untreated cotton plants (with a high density of SLWF) were generally lower then plants treated to obtain SLWF populations of 2.5, 5, and 10 per leaf; there were generally no significant differences in rates among the 2.5, 5, and 10 adults per leaf treatments.

In melons, the optimal threshold was been identified at 0.5 large SLWF nymph per 7.6 cm^2 leaf area. Additional research on action thresholds has been conducted on tomatoes, broccoli, and lettuce.

SLWF action thresholds for lint stickiness are less well-defined, possibly because of the difficulties in sampling stickiness as described above. Studies have identified trehalulose, melezitose, fructose, and glucose as the primarily sugars and the levels of these compounds was positively correlated with minicard sticky cotton ratings. Densities of SLWF adults and nymphs were also correlated with the presence of insect-produced sugars. Peak honeydew production occurs between 2100 and 1000 hours.

BIOCONTROL-WHITEFLY, a menu driven interactive DOS program for personal computers has been developed in Arizona. The program bases SLWF population growth on temperature and host plant. Up to five different species of parasites and predators each can be simulated simultaneously. Option are available for augmentative releases of parasites or predators, adjusting population predictions, and pesticide applications. Daily predictions of SLWF, parasite and predator populations, parasitism rates, and accumulated heats are saved into ASCII files. The program can also be used to estimate migration rates of adults because BIOCONTROL-WHITEFLY tracks a population's intrinsic rate of increase. Significant departures from population predictions by the model can be attributed to migration. Operational models are also in various stages of development in Texas, Florida, and Mississippi.

Another important factor influencing silverleaf whitefly population dynamics is the dispersal characteristics of the species. In the Lower Rio Grande Valley of Texas, the increase and decline of dispersing whitefly adults was associated with the increase and decline of the cotton crop and trap counts were positively correlated with cotton acreage and defoliation near the end of the season. Other periods of intense SLWF dispersal appeared to be associated with cabbage and melon harvest. In Arizona and Sonora, Mexico, few SLWF adults dispersed into cotton when melon or squash plantings remained in good growing condition but dispersal occurred when the melon or squash crop growth pattern weakened.

In Arizona, flight chamber studies showed comparable flight from 0600 to 1900 h, but flight duration was maximum between 0600 and 1000 h. Males flew longer than females and their mean flight duration remained constant throughout the day. Females flew longer from 0600 to 1200 h than from 1300 to 1900 h. A small percentage (< 5%) of both sexes were capable of sustaining flight for more than 2 h. Whiteflies reared on senescing plant tissue exhibited greater takeoff rates and longer phototactic flights up to 4 days following adult eclosion when compared to individuals reared on vegetative plant tissue. Thereafter, individuals reared on vegetative tissue exhibited greater response levels. Whiteflies reared on vegetative tissue weighed more and survived longer than did whiteflies reared on senescing tissue. Over the course of flight phototactic and photokinetic responses to overhead light in the chamber declined and flight instability increased. Although males and females displayed similar flight characteristics, females exhibited a greater rate of climb than did males, and for both sexes individuals that flew longer than 25 min had a greater rate of climb than did individuals that flew for less than 25 min. SLWF whiteflies were also found to sustain flight at temperatures up to 47° C. Variation in response to a light wave band simulating vegetative cues during phototactically-oriented flight for 3 s during each minute of flight resulted in 76% of the individuals landing on the target within three presentations. Another 18% of the whiteflies displayed an intermittent attraction to the host cue, and 6% displayed a response that historically has been considered to be indicative of migration.

Under greenhouse conditions whiteflies taking off and exhibiting a positive response to sky light was greatest from 0830 to 1000 h. During peak flight activity less than

5% of the population engaged in phototactic orientation and this response was short-lived (approximately 1 day). Temperature accounted for 75% of the variability in whitefly ascent. Addition of solar radiance, relative humidity and time of day explained only 6% more of the variation in ascent. Males were more prevalent on plants, whereas females were much more prevalent among whiteflies responding to sky light. A higher percentage (87%) of the females displaying a phototactic response contained eggs when compared to females remaining on their host plant. Whiteflies exhibiting a phototactic response in the greenhouse were more likely to exhibit long-duration, phototactic flights in a vertical flight chamber, compared to individuals that remained on the host plant.

In Arizona, Day-Glo® dust marked whiteflies in the field were captured on sticky traps at distances of up to 12 km from their point of origin. Small suction traps caught live whiteflies 1 km from the source field. Prevailing wind direction and trap catches were highly correlated. Distance traveled had no effect on adult female longevity. Female whiteflies collected from all distances were capable of producing offspring. Within a 3-hr time period whiteflies can travel as far as 3.0 km. There was no relationship between distance flown and egg load but egg loads in field collected whiteflies were significantly different from egg loads in trapped whiteflies. Female whiteflies collected away from the source field had a significantly higher lipid content (+ 27%) than individuals collected in the source field, if lipid content was corrected for weight but not when lipid content was not corrected for weight. There was also no relationship between distance flown from the source field and lipid content. Adult female lipid content increased significantly in the first two days after emergence, but not thereafter. Whereas adult male lipid content remained constant during their adult lives. Lipid analysis of eggs showed that they could be important lipid sinks. Approximately 29% of the total lipids in females is tied to developing eggs in the females caught in traps. Whitefly populations marked with fluorescent dust in a field of cantaloupes were consistently caught in traps placed along transacts in a southwesterly direction associated with wind direction. The distribution of trapped, marked whiteflies on all days after marking was patchy. Traps in the immediate vicinity of the marked field caught more whiteflies than the daily median. Large numbers were also collected from around the periphery of the grid. Whiteflies were virtually absent in the center. These patterns confirm behavior observed in the laboratory, i.e., a portion of the population are trivial fliers that do not engage in migration, and a portion initially ignore vegetative cues and fly for a period of time before landing. Although whiteflies were caught in the most distant traps (4.8 Km away), few were found there indicating that under the test conditions this distance may define the limits of localized migration.

Female whiteflies had small but significant increases in egg-protein levels with longer flights and increasing weights. Premigratory whiteflies always had higher levels of egg proteins in comparison to settled whiteflies. Egg protein could occur in the fat body, hemolymph or in the form of mature eggs. The location, rather than the quantity of these egg proteins may be more important in affecting the behavior manifested.

Two peaks occurred in amino acids from phloem collections in melons: an initial large peak and a smaller peak associated with senescence. In young to mature plants, 23 amino acids were identified, 11 were found in almost all samples. In the last six weeks of the melon growing season, fewer amino acids were identified and their concentrations were reduced. In general, as amino acid concentration increased, so did the number of whitefly eggs laid. Perhaps, one or a combination of a few amino acids will prove indicative of egg-laying preference. As developmental time increased, emergence rate decreased, suggesting a possible connection to amino acid concentrations. Female and male weight were similarly related to amino acid concentrations.

When whitefly single pairs were placed on melon, in clip cages, no relationship was found between number of eggs per female and leaf age or between number of eggs retained and leaf age. However, when 10 pairs of whiteflies were placed in clip cages, fewer eggs were laid (per female) on older leaves and more eggs were retained in females placed on older leaves. The presence of more than four mature eggs inhibited long-duration flights but fewer than four mature eggs did not seem to inhibit the flight activity.

Cohorts of SLWF reared on were water stressed and nonstressed reared melon plants. Water stress melon plants were smaller and had fewer and smaller leaves. No difference in leaf water potential occurred between treatments before dawn (5.3 vs. 5.9 bar). At 1 p.m., leaf water potential was higher with water stressed plants (13.8 bar) than in non-stressed plants (7.5 bar). Water stress did not affect the weight of whiteflies developing on the plants, but peak emergence was delayed by approximately 1 d. Water stress did speed 3 d old whitefly ascent toward overhead white light but had no significant effect on flight duration for male or female SLWF. Whiteflies excreted half as much honeydew in 24 h on the water stressed plants than on those without water stress. Long duration flights were observed to be more prevalent in SLWF developing on older leaves. The lack of response to leaf water stress may indicate that whiteflies are sensitive to the duration and nature of leaf quality deterioration, and that they are able to compensate for temporary reductions in food quality.

**T. J. Henneberry contributed information on modeling and dispersal activities.*

Section B. Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus-Vector Interactions

Compiled by J. K. Brown and J. P. Shapiro
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BACKGROUND

Although *Bemisia tabaci* (*Genn.*) has been recognized since the turn of the century as a phytophagous pest and an important vector of plant viruses, this whitefly has become of national and international concern only during the last five years. The highly virulent biological type B (also *B. argentifolii*) was introduced into the U.S. and adjacent locales and has become established in cropping systems, worldwide. In the U.S., the sunbelt states of the mainland, the Hawaiian Islands in the Pacific, and Puerto Rico in the Caribbean Basin have experienced dramatic changes in cropping practices due to losses associated with direct feeding damage and phytotoxicities, and new virus diseases occurring in epidemic proportions as a result this virulent new whitefly. The B biotype of *B. tabaci* was designated as the distinct species, *B. argentifolii* of the *B. tabaci* species complex, and it is now recognized as one of the most important insect pests of vegetable and fiber crops in subtropical and fringe temperate agroecosystems. Members of the complex are the exclusive vectors of WFT geminiviruses, newly emerging plant virus pathogens of vegetable and fiber crops, worldwide.

The taxonomic synonymization by Russell (1957) of approximately nineteen genera and/or species into one taxon, *Bemisia tabaci* (Genn.) is historically suggestive of the prior recognition of an assemblage of closely related populations and/or sibling species having worldwide distribution throughout the tropical/subtropical latitudes. Although this whitefly has a documented composite host range spanning more than 500 plant species, host-related affinities among several populations, termed races or biological types, were also described. The latter terms were applied to *B. tabaci* populations with recognized host preferences that could not otherwise be differentiated. The concept of host races was primarily inferential due to the lack of corroborating evidence of morphological or genetic polymorphism. Indeed, there was no information available about genetic diversity or population structure in relation to host preferences of morphologically indistinguishable phenotypes. Improved knowledge of the taxonomy and systematics of this apparently highly polymorphic whitefly complex is a vital component of formulating valid taxonomic and phylogenetic decisions about this group. A clearer taxonomic perspective is the cornerstone of relevant scientific hypotheses, valid experimentation, and for understanding relevant biological, behavioral, biochemical, and physiological characteristics of this whitefly complex.

Development of timely and effective control measures to protect economically important food, fiber, and ornamental plants from this new whitefly pest and the emerging plant viruses that it transmits is dependent upon an improved understanding of many fundamental aspects of the biology and molecular biology of the whitefly as a pest and vector. Likewise, the virus pathogens, and the interactions between virus, vector, and the host plant must comprise a major focus toward reduced impact of the diseases. Reducing geminivirus disease incidence relies upon an understanding of underlying mechanisms involved in the transmission pathway and the basis for an exclusive specificity between geminiviruses and their whitefly vector.

This section of the National Five Year Plan has provided a nucleus for researchers investigating the identification of morphological characters for species/subspecies differentiation, the genetic diversity and development of molecular markers, the role of whitefly endosymbionts in vital biological processes, and their relationship to its fitness as a virus vector or to haplo-diploidy and arrhennotokus reproduction, the mechanisms of host-plant susceptibility and resistance, the physiology of host acceptance and utilization, and the anatomical ultra- structure of the whitefly with an emphasis on feeding, digestion, nutrient utilization, and virus-vector interactions. Another major and essential component of this section was the study of emerging plant virus pathogens, with a particular emphasis on WFT geminiviruses on a global basis. Research has been directed toward devising molecular methods for identification of new viral pathogens, the application of molecular epidemiological tools to permit tracking and detailed assessment of the virus pathogens, and the identification of molecular markers to facilitate inferences about molecular phylogeny of the subgroup III Geminiviridae. Combined with existing information about virus gene function, gene expression and its regulation, these new technologies are now being applied to the development of disease-resistant crop cultivars. Another critical area of focus concerned the mechanisms governing geminivirus-vector specificity, defining the transmission pathway in the whitefly vector, and a search for receptors of whitefly origin that interact with virus nucleocapsid amino acid epitopes during a successful transmission event. Interference with specific events during the transmission process is an area with great potential to devise universal disease resistance that relies on interference with geminivirus transmission by a single whitefly vector, worldwide. Also emphasized in this section were studies of the adaptation of *B. tabaci* to an apparently variable range of plant hosts, and understanding the complex array of insect-plant interactions affecting metabolic processes in both the whitefly and its host. Understanding the basis of host plant selection, nutrient requirements and utilization, and whitefly feeding behavior are needed to capitalize on mechanisms of host plant resistance.

Prior to the deliberate and organized research focus toward the *B. tabaci* species complex and the virus pathogens that it transmits, fundamental aspects of whitefly anatomy, behavior, biochemistry, biology, molecular biology, virus-vector interactions, and whitefly-host interactions were only peripherally studied. In five years, much progress has been achieved. Continued investigations, improved

infrastructure, and a greater understanding of all aspects cited above are vital to the development of sustainable management approaches focused on reducing the impact of the whitefly as a pest and vector in U.S. and international agroecosystems. Here, we outline specific contributions and prospective benefits of the research conducted under the Fundamental Research Section of The National Five Year Plan from its inception in 1992 through 1996.

RESEARCH CONTRIBUTIONS, BENEFITS, AND PERSPECTIVES

Whitefly Behavior

Host finding and acceptance. *B. tabaci* is strongly attracted to surfaces reflecting in yellow-green wavelengths at certain times and to blue/UV reflecting surfaces at others. Host acceptance or rejection seems to be largely due to taste response following short leaf probing in the mesophyll. The influence of host and host choice on whitefly fecundity was examined, and at times, eggs were deposited on plants suitable for adult feeding that were not conducive to progeny survival. AC feeding monitors were applied to correlate ovipositional activity with adult feeding patterns, and patterns of females are thought to be more indicative of ovipositional site preferences than of adult nutrition.

Feeding nymphs. Knowledge of feeding behavior has advanced, especially through histological study of nymphal feeding. Successfully established nymphs secrete a stylet sheath that is attached to a vascular bundle in leaves. Paths of penetration of nymph and adult stylets into leaves and vascular bundles were traced. The abundance of vascular bundles in various plant cultivars and species was correlated with the abundance and success of nymphs. The nymph stylet length from leaf surface to vascular bundle rarely exceeded 60 mm. The percentage of leaf surface area within a 60-mm reach of a vascular bundle in 6 host plant cultivars correlated positively with acceptance by nymphs. Elongated surface cells were associated with minor bundles and marked positions where nymphs penetrated. Nymphs targeted only minor vascular bundles, and stylets of surviving nymphs always reached bundles and phloem cells within. Surface structure and internal leaf structures influence the success of all developmental stages of whiteflies on host plants. In cotton, elongated epidermal cells and aerial trichomes are associated with vascular bundles, and eggs were deposited proximal to vascular bundle-associated epidermal cells. Crawlers settled at feeding sites under vascular bundles.

Adults. It has been assumed that adult whiteflies are phloem feeders, but definitive data were lacking. Studies now indicate evidence for some intracellular penetration during stylet probing, but the potential significance of these observations to feeding disorders and virus transmission efficiency has not yet been addressed. Research with electronic feeding monitors is examining feeding activity patterns that correlate with external stimuli and behavior. Studies on feeding behavior and location of adult whiteflies on plants indicate that lower surfaces of the youngest leaves of most plant species tested are preferentially selected among other locations. Feeding sites were concentrated in areas containing vascular bundles. Adult whiteflies prefer sites where vascular bundles were closer to the leaf surface, adding additional credence to the observation that the under surface of the leaf is the optimal ecological niche for *B. tabaci.* Adult whitefly behavior was correlated negatively to geotropic factors, and positively in response to leaves with the greatest osmotic potential.

Artificial rearing and feeding systems. Several artificial feeding systems have been established to evaluate the effects of chemical, toxins, and antibiotics on whitefly fecundity, development, and honeydew production, and to study feeding behavior relative to intake of phloem sap and geminiviruses in phloem sap.

One feeding chamber experiment tested semi-synthetic diet presented through a Parafilm membrane and demonstrated for the first time an ability to rear whiteflies successfully from egg to adult in the absence of a host plant. Egg hatching rates were 2-50%, and presence of specific dietary constituents were critical to development past the third instar. With this chamber, feeding behavior of immatures was studied using ingestion of fluorescent markers, and feeding structures active during ingestion and processing of synthetic diet have been video-recorded.

Microorganismal toxins were assayed against adult *Bemisia argentifolii* in a new assay. Destruxins from *Metarhizium anisopliae* showed activities equivalent to those of the insecticides Imidocloprid and Ivermectin and may be useful against whiteflies. Delta-endotoxins from *Bacillus thuringiensis* showed no activity.

Development of artificial feeding apparatus and artificial diets for whiteflies and their natural enemies will also permit mass rearing of natural enemies and experimental evaluation of dietary composition critical for development and reproduction. A diet was developed for a coccinelid beetle predator that permitted second instar larvae to develop into adults that could feed on whiteflies.

Mating and oviposition. Data on mating behavior and effects of mating on fecundity, viability, and population structure of whitefly on cotton indicate distinct behaviors for the B biotype and other whitefly genera, however, these data need to be evaluated for genetically diverse whitefly populations or species within the *B. tabaci* species complex because host plant effects strongly influence parameters. Whitefly are haplo-diploid and exhibit arrhenotoky in that unmated females produce only male offspring and mated females produce different proportions of male and female offspring, a phenomenon thought to be dependent upon environmental influences. Recent studies with the biotype B demonstrated that viability of eggs can be much lower from an unfertilized female. Oviposition rate during the first days of adult life is not influenced by mating history. Mating behaviors for three whitefly species were captured on film using a video recorder attached to a binocular microscope. Leaf age and position on the plant influenced oviposition rates. Definitive differences in behavioral patterns and temporal modulation of behavioral activities were documented during different stages of courtship and copulation aspects of mating. Elucidating

the behaviors, cues, and barriers involved will facilitate precise understanding of mating behaviors between males and females of different biotypes or species within the *B. tabaci*. complex. The basis for apparent reproductive isolation between certain populations of *B. tabaci* is not known, and has been another major confounding factor in resolving the taxonomic status of *B. tabaci*.

Reproduction and development. Growth and development of laboratory populations of *B. tabaci* were compared on cucurbits by confining A and B biotype adults in separate clip cages to permit oviposition on the same host leaf, on different host leaves, and on different plants. B biotype immatures developed faster than did the A biotype under all tested conditions. Development of the A biotype was not accelerated on plants pre-conditioned by B biotype feeding.

Sex pheromones. The existence of a sex pheromone has been reported for greenhouse whitefly, but evidence for a similar pheromone in *B. tabaci* is circumstantial. Behavioral observations of the B biotype suggest an arrestant may be produced by females. One attempt to characterize a whitefly pheromone by gas chromatography indicated females did not produce volatiles active over a distance greater than one centimeter. Results of yet another study indicate a pheromone may yet be involved.

Post-hatching behavior. Morphologies of immatures were influenced by the number of trichomes encountered by crawlers. Increased production of waxy cuticular structures or setae on the pupal exuviae was positively correlated with number of contacts with leaf surface obstructions providing the first demonstration that specific behaviors influences certain morphological adaptations. Stimuli positively correlated with prolific setal development were cuticle geography, degree of pubescence, and crowdedness. This study demonstrated for the first time that particular external stimuli govern the development of and size and morphology of several characters considered key to taxonomic identification, and extended the *a priori* recognition of morphologically-based phenotypic plasticity in the fourth instar.

Tritrophic level interactions. While earlier work on parasitism mostly ignored the contribution of host plant diversity, the role of specific host plants in determining the success of parasitoids is now being studied. Several key observations may indicate reasons for failure of particular parasitoids when introduced from certain plants in that definite effects of host plant on parasite searching and oviposition behavior were shown. Another study indicated whitefly adults avoided plants previously occupied by green lacewing, *Chrysoperla carnea*, suggesting allelochemical communication mediation.

Biochemistry

Digestive system. The constituents of phloem sap ingested by the whitefly, and composition of whitefly honeydew have been studied. Certain amino acids in phloem sap were found in reduced forms in whitefly excreta, suggesting some host amino acids are metabolized in the whitefly. In addition to several common carbohydrates, the disaccharide: trehaulose, previously associated with certain microorganisms but not found in insects, was identified in whitefly honeydew. In a study of digestive enzymology utilizing numerous proteinaceous and synthetic substrates, serine proteinase activity was not detected in whiteflies. The presence of amylase activity in *B. tabaci* indicates that carbohydrates other than those in phloem sap may contribute to whitefly nutrition. Kinetics, substrate specificity, pI, pH optimum, weight-specific activity and stage-specific activity have been determined for whitefly amylase. Chloroplast starch destruction at these feeding sites indicate that whiteflies derive some nutrients from the host mesophyll. Plant proteins and lipids are not generally recognized to be present in high concentrations in plant phloem, but recent findings suggest otherwise. Sulfur-radiolabeled proteins from cotton leaves or amino acids were taken up by adult whiteflies feeding through Parafilm. Radiolabel (16% from protein and 25% from amino acids) was excreted in honeydew, mostly as free amino acids, but radiolabeled protein was found in whiteflies. Potential targets of these studies are alteration of plant leaf surface chemistry to repel feeding and oviposition, biochemical disruption of stylet sheath formation, inhibition of enzymes responsible for damage at the feeding sites, or increased sap viscosity to reduce feeding rates.

Whitefly honeydew. Honeydew from A and B-biotypes of *B. tabaci* adults and nymphs fed on cotton were analyzed. The excreta is a complex mixture of at least 40 different sugar components, some of which are unique to *B. tabaci* and some to the B biotype. Trehalulose, a trehalulose derivative, polyols, nonreducing oligosaccharides, and reducing monosaccharides and oligosaccharides were detected. Oligosaccharides having three to six monosaccharide units were found in the honeydew of whiteflies fed on cotton. Excretion of honeydew by whiteflies creates postharvest problems in cotton due to contamination of lint by large oligosaccharides and the smaller oligosaccharides, trehatulose and sucrose. The structure of a tetrasaccharide unique to honeydew was solved and there is evidence that this sugar contains fructose. Knowledge of the structure of honeydew carbohydrates was used to combat sticky cotton with Solvay Enzyme B.

Wax glands and surface lipids. Ultrastructural studies of the external morphology and the secretory cells of the wax glands indicate that *B. tabaci* is similar to the greenhouse whitefly with respect to age-dependent wax production. The surface lipids of the two species were compared and small amounts of saturated hydrocarbons were characteristic of lipids for both. *T. vaporariorum* adults had C_{32} alcohols, C_{32} aldehydes, and C_{42} wax esters, whereas *B. tabaci* lipids had C_{34} alcohols and aldehydes, and C_{46} wax esters. In both, a C_{20} fatty acid was the major component of the predominant wax ester. The predominant wax esters were C_{46} and the major acid and alcohol moieties in the esters were C_{20} and C_{26} length chains, respectively. Identification of lipid compositions on the surface of fourth instar B biotype nymphs and exuviae indicated long chain wax esters predominated, but aldehydes, hydrocarbons, and alcohols were also found on nymphal surfaces and inside and outside of exuviae. A

study of the composition of surface lipids and waxes on external surfaces of B biotype adults showed there was no apparent effect by host plant on composition for males or females. Analyses of cuticular waxes from adult and immature whiteflies did not permit differentiation among biotypes or even species, but did permit effective identification to the genus level.

General esterases. Composition of the diagnostic general esterase bands resolved by native PAGE were characterized, and differences in PI, size/charge isomeric relationships, and enzymatic activities of AChE from both biotypes were documented. Inhibition studies indicate an altered isoform of AChE from the B biotype.

Endosymbionts. Mycetome-like organs containing prokaryotic-like and pleomorphic subsets of microorganisms were observed in immature instars, and at the distal tip of each egg as in other homopterans. Transfer of endosymbionts in mycetocytes from the female to developing ova was discovered to be a process that occurs continuously, prior to oviposition. Mycetocyte-containing bacteria were observed in oocytes inside a common membrane in the region that becomes the pedicel end of the egg. In the final stages of ovum development, the plasma of the oocyte completely surrounds the mycetocyte and the chorion thickens. Ooctyes with mycetocytes were present in adult females 16 hr after emergence, and none were observed in individuals that were less than 2 hrs old.

Antibiotics known to have a negative impact on prokaryotic processes and metabolism were detrimental to whiteflies, whereas those specifically inhibiting prokaryotic cell membrane synthesis or affecting cell walls did not appear to affect whiteflies in measurable ways. These negative effects are attributed to mortality of the primary endosymbiont in whiteflies. Partial curing of adults resulted in a reduced vigor of offspring of treated adults, and lowered intensity of phytotoxic silvering of squash leaves.

The unusual sugar disaccharide, trehalulose, is found in large quantities in whitefly honeydew, and its production is postulated to be through an interaction between the whitefly and obligate intracellular endosymbionts. Candidate compounds tested against whiteflies were two lectins, a fungal toxin, and one venom, and only the latter showed activity against putative whitefly symbionts, based on reduced honeydew production. Intact mycetomes isolated from surface-sterilized adult and nymph whiteflies and eggs converted sucrose to trehalulose, glucose, and fructose *in vitro*. Under these conditions, trehalulose was produced by fermentation of sucrose and raffinose.

Morphotypes. Morphological variants of putative endosymbionts were identified in populations of the *B. tabaci* complex. Differences in number, morphology, and relative frequency were documented. Three morphoforms were observed among the whiteflies examined: coccoid C1, coccoid C2, and a pleomorphic P form. Two forms, C1 and P, were associated with the B biotype (also *B. argentifolii*), whereas all three forms, C1, C2, and P, were present in two New World populations, the A biotype and the Jatropha biotype from Puerto Rico.

VLPs. Virus-like particles (VLPs) of approximately 30 nm in diameter were observed by TEM in the monophagous Jatropha biotype of *B. tabaci* from Puerto Rico. VLPs were associated with mycetocytes containing endosymbiotic bacteria. This is the first report of VLPs associated with this genus of whitefly; it is not known if the virus is pathogenic to the whitefly host.

Taxonomy and Systematics

The taxonomy and systematics of whiteflies has been problematic and difficult to reconcile due to extreme plasticity of key morphological characteristics that respond to features of the host plant. As a result, in 1957, nineteen described genera and/or species were synonymized into a single taxon *Bemisia tabaci* (Genn.), having a subtropical distribution restricted to the 30th degree parallels north and south. Since the introduction and widespread distribution of the B biotype (*B. argentifolii*) in subtropical and fringe temperate zones and temperate climate greenhouses beginning in 1986, a wider distribution of this whitefly is now recognized, and evidence that *B. argentifolii* is one of numerous siblings species within a proposed *B. tabaci* complex has challenged the notion of a single species for the first time since the synonymization.

Protein and biological polymorphisms and first definition of the B biotype. Genetic and biological polymorphism were studied by examination of host range, general (non-specific) esterase profiles, and compatibility in mating for a collection of *B. tabaci* from representative host plants and geographic locations around the world. Polymorphism within the species was highly evident in all characters examined. An 'A type' profile was arbitrarily assigned to the pattern obtained for the prototype Arizona *B. tabaci* population during its initial comparison with a population originating from greenhouse grown ornamentals. This population, thereafter, tentatively called the 'B type', was suspected to be unique from the endemic Arizona 'A population' based upon phenotypic differences initially noted for these two populations of *B. tabaci* present in Arizona in 1988. Unique general esterase profiles were reproducible within numerous populations maintained in colonies and sampled several times over the course of two years. Several populations had the same esterase profile and were indistinguishable from that discovered previously for the B biotype from Arizona. From these studies, a diagnostic profile was established for the B biotype and this banding pattern was shown to be consistently associated with populations of B. tabaci that induced silvering in squash (*Cucurbita* species). Collectively, the unique general esterase profile and SSL induction were established as diagnostic for the B biotype whitefly. Discovery of additional unique esterase profiles among the Arizona-UK collection of populations has permitted arbitrary assignment of 'types' by alphabetical designation in the order of discovery. Biological traits and detailed genetic studies have been pursued or are underway for a suite of biotypes, now the best characterized collection of *B. tabaci* from different biogeographies. Populations that exhibited unique esterase profiles often showed differences in host range and preferences, however all but two were polyphagous. The monophagous populations

were from *Asystasia* plants in Benin, while the other was the previously described Jatropha race from Puerto Rico. Populations with unique esterase profiles did not produce female progeny in mating studies, whereas several populations collected from different locations and hosts, and identified as B types by esterase and SSL assays produced female progeny in all crosses examined. Results of these studies provided the first evidence for a greater degree of genetic and biological diversity within the *B. tabaci* taxon than previously known, demonstrated incompatibilities in mating between certain populations, and provided a diagnostic method for identifying and tracking the distribution of the B biotype.

Distribution of B biotype by diagnostic esterase electromorph and SSL bioassays. The diagnostic esterase electromorph of the B biotype in combination with induction of the SSL symptom phenotype in *Cucurbita* spp were used to map the distribution of the B biotype from 1988-1996. This whitefly is present in field crops in mild climate regions of North America (Mexico and the sunbelt states of the U.S.), South, and Central America, the Caribbean Basin (Greater and Lesser Antilles), all countries in the mild climatic zones of the Mediterranean Region, in most countries in the Middle East, in Japan, in Australia, and most recently, the B biotype was discovered in Pakistan. This whitefly is also established in ornamental and vegetable production greenhouses in the U.S., European Community countries, and The Netherlands, and other subtropical locations, worldwide. Another outcome was the discovery of many unique non-B like electromorphs in populations, world-wide, corroborating findings from molecular and biological studies in which variability among *B. tabaci* populations occurs to a greater degree than previously recognized.

IEF. Isoelectric focusing of enzyme-encoding loci of the A and B biotypes indicated that allelic polymorphisms were present for 8 of the 14 enzymes evaluated. Fixed differences between A and B were present at three (EST IV, PGI, and PGM) of the eight polymorphic loci. Calculated of allelic frequencies of A and B yielded a genetic distance (D) value of 0.24 and falls within the range(0.1-2.0) estimate for separate species. These data corroborated previous findings of protein polymorphism between the A and B biotypes and provided the first quantitative estimates of degrees of genetic polymorphism between these two whiteflies.

RAPDs. Polymerase chain reaction (PCR) and detection of randomly amplified polymorphic DNA (RAPDs) were used to identify and quantify arbitrarily targeted sequences in whitefly DNA extracts. Several laboratories conducted studies to evaluate degrees of genetic diversity among A and B biotypes in the U.S., and among *B. tabaci* collected from field sites throughout the world. Similarities and dissimilarities in loci were identified between the A and B biotypes. By this genetic analysis by RAPD-PCR most populations examined clustered by either a New or Old World origin, but several populations are either split, or form a continuous distribution, depending on type of analysis applied to data sets. A principle component model generated genetically different clusters within twelve populations of *B. tabaci* and separated six distinguishable groupings: A and B like biotypes from Central and North America, and four other distinct banding patterns for whiteflies either from Spain, Egypt, India, or Nepal. These results corroborated previous evidence for polymorphisms by esterase, IEF, and biological phenotypes.

Molecular markers and sequences. Conserved molecular sequences from 18S ribosomal RNA (rRNA) and a more variable D2 expansion segment of the 28S rDNA were compared for whiteflies within the superfamily Aleyrodidae, including the A and B biotypes of *B. tabaci.* Results of genetic distance calculations indicated that based on the highly conserved 18S rDNA, *B. tabaci*, *Siphoninus phillyreae* (ash whitefly), and *Aleurodes spiraeiodes* (iris whitefly) appear to be descendant from an immediate common ancestor. *T. vaporariorum* showed sufficient genetic distance from other whiteflies to suggest descendence from a distinct and more ancient progenitor. Only a single nucleotide difference was found for *B. tabaci* and *B. argentifolii.*

DNA sequences of the (rRNA) of an endosymbiont of *B. tabaci* were compared to sequences from *S. phillyrea, and T. vaporariorum.* Sequence similarities indicate that the endosymbionts from these three whiteflies are related and constitute a distinct lineage within the Gamma subdivision of the *Proteobacteria.* Sequences from the endosymbionts in A and B biotypes of *B. tabaci* are unrelated to the analogous endosymbionts in aphids or mealy bugs. The eukaryotic genes for the 18S rRNA from the ash whitefly and both biotypes of *B. tabaci* were compared to the sequence from the 16S rRNA of their respective endosymbionts. Genetic distances between each host and its respective endosymbiont indicated evolutionary divergence in whitefly hosts and their endosymbionts is congruent, and that A and B biotypes are conspecific.

A laboratory collection of *B. tabaci* was evaluated with respect to DNA sequence similarity of a gene fragment of the mitochondrial 16S ribosomal subunit, postulated to constitute a region for discrimination at subspecies levels. Four major subgroups were supported by parsimony analysis: three groups from the Old World (including the B biotype), and one group containing all New World (including the A biotype). Based on 16S mtDNA analysis of additional populations, more subgroups may be feasibly supported. The B biotype consistently clustered with other Old World whiteflies in the Middle Eastern group, suggesting a similar origin.

Mating studies. Several laboratories conducted mating studies between A and B biotypes of *B. tabaci,* and results are somewhat variable. In one study, crosses between unmated virgin males and females yielded predominantly male progeny, and although female progeny were present at the rate of 1%, no evidence of viability was obtained. Diagnostic A and B esterase electromorphs were used to confirm the genetic identity of parents and progeny, and offspring had an esterase phenotype identical to their female parent. Control AxA and BxB crosses yielded nearly equal proportions of both male and female, depending upon time of the year. Two other laboratories conducted similar

mating experiments between A and B biotypes and observed only male progeny. These studies, collectively provided the first evidence that the two biotypes may be distinct species. In yet another study, mass mating experiments were conducted and a hybrid or segregated population detected by general esterase analysis was suggested. Similar hybrid patterns were observed among *B. tabaci* collected from Israel, Nigeria, and the USA. These latter data are inconsistent with experiments conducted by other laboratories in that here, strict reproductive isolation was not observed. Factors contributing to possible development of hybrids have not yet been identified.

Classical morphological assessment of fourth instars. Morphological studies for taxonomic considerations of the A and B biotypes focused on the pupal vasiform orifice, and mapping of setae and pore arrangements. Morphometric analysis of data produced such widely scattered loci that the two strains could not be separated. The submarginal setae, ASMS4, present in the A biotype, in type material *Bemisia tabaci* from Greece, and in type material *Bemisia poinsettia,* is absent from the B biotype 95% of the time. Results indicate that because the character is not present or absent 100% of the time, the ASMS4 setae are minute, and their expression are affected by environment, it will not be useful as a taxonomic character for differentiating the A and B biotypes, or for recognizing sibling species within the proposed *Bemisia tabaci* species complex.

Morphological characters of whitefly fourth instar pupal were also investigated by scanning electron microscopy (SEM) to assess at high resolution key morphological characters used for taxonomic consideration of *Bemisia* spp. Characters examined were those in the species description of *B. argentifolii* that (along with genetic differences and reproductive isolation reported elsewhere) establish *B. argentifolii* as a separate species. Characters examined were the anterior margin setae four (ASM4), anterior and posterior wax margins, dorsal setae and posterior submarginal setae. Measurements taken for individuals (n=10) from seventeen populations viewed by SEM and statistical and parsimony analyses of data indicated the ASM4 were generally but not always absent from non B biotypes and from *B. argentifolii*, and were present in most but not all individuals of the A biotype and in those from A-like, New World populations. Neither the size of anterior and posterior wax margins were unique to any biotype regardless of location, and so are not distinctive characters for consistent differentiation of populations. The character examined also varied in different populations depending on host plant, and/or on absence or degree of leaf pubescence, and with degrees of crowdedness.

***B. argentifolii* as a species separate from *B. tabaci*.** Measurable degrees of protein polymorphism and evidence that the A and B biotype do not mate and produce viable offspring provided the most convincing evidence for taxonomic separation of the A and B biotypes of *B. tabaci* into two distinct species. In 1993, the taxon epithet *B. argentifolii* was proposed to distinguish the tentatively termed type B as a unique and separate species in the genus *Bemisia* and in 1994, a description of the new species was published. There are no morphological characters yet discovered that permit unequivocal differentiation between *Bemisia tabaci/B. argentifolii.* Recent preliminary evidence has been obtained from another study by sequence comparison of a molecular marker within the mitochondria 16S ribosomal DNA, and results indicate a high degree of variability among *B. tabaci* populations from representative collections, worldwide. A heuristic search using various parameters consistently identified the same large single island of most parsimonious trees of length 740, from which a consensus tree was derived. Essentially four groups were well-supported: a group of whiteflies from India, a second containing those from Sudan, a third from Middle East/Mediterranean Region plus the B biotype, and a fourth group containing whiteflies from North America, Central America, and the Caribbean Basin plus the A biotype. The B biotype clearly clustered with the Middle East/ Mediterranean whitefly group, suggesting it is of Old World origin. The calculated genetic similarities for representative populations ranged from 0.79 to 0.98, and sequences in Old and New World whiteflies were more similar to each other than between the two groups. For this reason, a proposal has been made to consider this group of closely related whiteflies as a species complex, or sibling species. Additional data are now needed to test this hypothesis.

Natural enemies and molecular markers. A rapid diagnostic molecular diagnostic method has been developed by which to differentiate select natural enemies of the *B. tabaci* complex. Included in the analysis were two genera of natural enemies collected from many different countries during foreign exploration efforts in both Old and New World sites. Genetic fingerprints or RAPDs patterns groups have been established using RAPD-PCR. This method yielded identification of 18 distinct RAPD pattterns for *Encarsia* populations and 12 patterns for *Eretmocerus* spp. Genetic markers are invaluable for the rapid identification of natural enemy populations collected from around the world, and facilitate monitoring of natural enemy populations maintained for evaluation for the first time. This approach is also highly useful for tracking natural enemies following release into field sites for the control of *Bemisia* spp.

Phytotoxic Disorders and Host Physiology

The squash silverleaf (SSL) and uneven ripening of tomato (TUR), (also known as irregular ripening) disorders were first observed widespread in Florida in 1986-87, were documented in Puerto Rico, the Dominican Republic and the Eastern Caribbean for the first time in 1988-89, in the sunbelt states of the Southwestern U.S. in 1988 (greenhouses) and 1990 (fields), and Hawaii (1993). Several other phytotoxic disorders are associated with feeding by *B. tabaci*: stem streaking in cole crops documented in Arizona and California in 1990-91, pale lettuce in Hawaii (1993), and bleaching of leaves in many ornamentals, worldwide beginning in 1987. Chlorosis and stunting have been reported in tropical fruit species, shrubs, and trees in the U.S. and Caribbean Basin.

Pathogenesis and biochemistry. Direct toxicogenic effects of the B biotype are expressed as uneven ripening in tomato, silverleaf in squash, stem streaking and thickening in *Brassica*, and paleness of leaves in lettuce and other composites. Pathogenesis-related proteins are typically sequestered in vacuoles or transported out of cells into the intercellular fluid (IF). The IF from silvered leaves of B biotype-infested cucurbits contained induced proteins of 31K and 70K Mr, whereas a characteristically prominent constitutively expressed protein (60K) was shown to be absent. In cucurbits, several natural products (alpha-tocopherol, squalene, and linolenic acid) were analyzed in developing leaves after whiteflies fed on lower leaves. Quantitative changes in these lipids may have nutritional consequences for the whitefly and/-physiological implications for the host plant. Linolenic acid and alpha-tocopherol (vitamin A) may induce host defensive responses and serve as vitamins for whiteflies, while squalene is a precursor of sterols which serve as critical structural components of plant cells and are also required by insects. Foliar application of plant growth regulators chlormequat chloride (Cycocel) and paclobutrazol (Bonzai) induced leaf silvering in cultivars of the Cucurbitaceae that are highly susceptible to whitefly-induced squash silverleaf. The temporal development and cytopathic effects of the two types of silvering were similar but the general plant physiological responses were different. Cycocel and Boni are gibberellic acid (GA) antagonists, indicating that part of the phytotoxic response to whitefly feeding may be due to altered GA metabolism. Studies of protein expression in tomato indicated that several proteins were induced by adult and larval feeding. Though total leaf protein decreased with whitefly feeding, enzymatic activities of chitinase, peroxidase, beta-1,3-glucanase, and chitosanase were greater than for whitefly-free controls. Immunoblots specifically identified two of the four proteins induced within 24 hours as a chitinase, a glucanase. Chitinase and peroxidase activities were reduced in the IF from whitefly-infested cucurbits. Characterization of systemically induced proteins elicited in response to whitefly feeding offers fundamental information about phytotoxicity and non-specifically induced resistance to pathogens.

dsRNA. The crop disorders squash silverleaf (SSL) and tomato uneven ripening (TUR) are associated with feeding by the B biotype. This biotype also contains a unique double-stranded RNA (dsRNA), and a relationship between the expression of dsRNA in the whitefly and induction of SSL was postulated. However, the significance and origin of dsRNA is not yet understood. Colonies of the B biotype *B. tabaci* contained dsRNA regardless of their geographic origin. dsRNA has not been detected in the A biotype, nor does the A biotypes acquire dsRNA or the ability to induce SSL after feeding on SSL-affected plants. Electron microscopy studies have not revealed any virus or virus-like agents in plants affected with SSL or with whiteflies fed on SSL-affected plants. Cytological and physiological studies in squash plants indicated that host cell development and senescence are directly affected by B biotype feeding. Translocatable factors stemming from whitefly-plant interactions may be responsible for systemic effects of the phytotoxic symptoms, instead of a toxin(s) produced by the whitefly alone.

Molecular biology. Differential display (reverse transcription and PCR amplification of transcripts) was used to investigate the molecular basis of TUR through comparative analysis of RNA expression in whitefly-infested or uninfested tomato. Expression of the defensive gene *LAP* was suppressed in plants infested with immature *B. argentifolii* and challenge inoculated with *Pseudomonas syringae*. It is hypothesized that insensitivity to ethylene of tomato fruit from TUR plants is associated with suppression of E8 gene expression and lowered a "perception" of ethylene levels. Reduced expression of polygalacturonase, an enzyme crucial to certain aspects of tomato fruit ripening, was also observed.

Virus Diseases

Whitefly-transmitted (WFT) geminiviruses. Diseases of vegetable and ornamental crops caused by the WFT or subgroup III members of the Geminiviridae were reported in Arizona, Florida, Texas, and throughout the Caribbean Basin and Mexico. In Arizona, molecular cloning and characterization were the focus for isolates of cotton leaf crumple, squash leaf curl, and an uncharacterized geminivirus of Solanaceae. Studies were initiated to identify geminiviruses of cotton, kenaf, pepper, squash, tomato, tomatillo, watermelon, and weed species in Texas. and to determine the epidemiology of squash leaf curl in cucurbits. Studies in Florida concentrated on determining experimental and natural host ranges and identification of sources of inoculum for tomato mottle virus. From these studies, it is known that TMoV infects species within the Solanaceae and Leguminosae, and that the most important source of TMoV inoculum is infected tomato fields. TMoV has been cloned and sequenced and has been shown to be related to other New World bipartite WFT geminiviruses. Breeding for virus resistance/tolerance in tomato was initiated with *Lycopersicon chilense* as a potential source of resistance gene(s). Engineered pathogen-derived resistance approaches have made promising strides using expression of mutant *CP*, *BC1*, and *Rep*. PCR methods were applied to study the epidemiologies of tomato yellow leaf curl virus (TYLCV) in Egypt and the TMoV in Florida, and were used in the detection of these viruses in plant hosts and the whitefly vector.

An epidemic in bean caused by Macroptilium mosaic geminivirus were reported in Florida for the first time. A recently introduced strain of bean golden mosaic virus from the Caribbean Basin and is distinct from the BGMV-FL strain. A strain of TYLCV, nearly identical to TYLCV-Israel, was found for the first time in the Dominican Republic, Jamaica, and Cuba

Non-geminiviruses with *Bemisia* or non-*Bemisia* vectors. Lettuce chlorosis disease, caused by a new closterovirus, was documented in several vegetable crops in southern California. This virus is now known to be phloem-limited, can be transmitted by the A and B biotypes of *B. tabaci*, and has narrow host range that does not include cucurbits. It is not serologically related to any well-characterized closterovirus, has a ssRNA genome of 8.0 kb, and a 32 kDa coat protein gene. Information about

the distribution, disease incidence, and severity of these two viruses has not been determined.

A new WFT closterovirus, tomato infectious chlorosis (TICV) was discovered in coastal California tomato greenhouses and is transmitted by the greenhouse whitefly, but not *B. tabaci.* The virus was also identified in tomato greenhouses in Italy.

Molecular Epidemiology

A PCR technique was developed for universal detection of WFT geminiviruses. PCR primers target the core region (nts 494-1048) of the capsid protein gene, the most highly conserved gene among subgroup III viruses. PCR products of diagnostic 550bp size indicate positive infection. Fragments are cloned and DNA sequences obtained to verify identity with sequences from well characterized viruses. A collection of core coat protein gene sequences has been established in a database. This database will be useful for geminivirus identification, molecular epidemiological studies, and for making predictions about phylogenetic relationships between geminivirus isolates. Among isolates collected and analyzed from New World sites, all but one virus, now known to be introduced into the Caribbean Basin from the Eastern Hemisphere, cluster with New World viruses. This suggests that the majority of viruses problematic in the U.S., Mexico, and Caribbean Basin originated in the New World, and are not introduced viruses. Further, these data extends the hypothesis that recent epidemics in the New World are primarily the result of indigenous viruses that rarely reached epidemic status in the past due to mobilization by new whitefly biotypes and altered disease pressures. Cloning and sequence of a second key region of the genome, the common region, are now underway for the same library of geminiviruses for identification and to provide a second molecular maker in a key region of viral genomes. Comparative analysis of core coat protein and common region sequences permitted delineation of (putative) genetically related subclusters within the WFT subgroup, and indicates a wider range of variability within the subgroup than previously thought. It is hypothesized that the ability to define WFT geminiviruses as constituents of particular genetic subclusters by key viral sequences will permit a better understanding (inferred) evolutionary relationships between these viruses, permit the early recognition of new and emerging viruses, and also suggests a possible strategy for selecting a range of prototype isolates for classical breeding or engineered resistance efforts.

Virus-Vector Interactions

Virus-vector studies. The Florida isolate of bean golden mosaic virus (BGMV-Fl) was shown to be transmitted by the B biotype of *B. tabaci*, and once acquired, is transmissible for the life of the vector The B biotype was demonstrated to be capable of acquiring and transmitting two unrelated geminiviruses of tomato from a mixed infection. Detection of geminivirus DNA in individual whiteflies given various acquisition access periods on infected plants was demonstrated using virus-specific primers and PCR reaction.

The B biotype was reported to be a poor vector of the lettuce infectious yellows virus (LIYV), previously a serious virus pathogen affecting many crops in the desert Southwest of the U.S.. This discovery may explain the decrease in LIYV disease incidence since the establishment of the B biotype in Arizona and California in 1989-90. In contrast, an unprecedented increase in WFT geminivirus diseases is directly associated with the recent, widespread distribution of the B biotype in the U.S. and adjacent locales in Mexico and the Caribbean Basin; hence the B biotype is an effective vector of WFT geminiviruses indigenous to New World sites.

Mechanism of whitefly-mediated gemini-virus transmission. A novel simulated transmission chamber was used to examine several steps in the transmission pathway of geminiviruses in the whitefly vector *B. tabaci* and the greenhouse whitefly- a non-vector of geminiviruses. PCR and geminivirus specific primers was used to amplify a 550bp diagnostic fragment of SqLCV coat protein gene in vector and non-vector whiteflies. In time-course studies, virus was detected in whole body extracts, honeydew, saliva, and hemolymph of the vector, whereas, in non-vector whiteflies, virus was detectable in body extracts and honeydew, but never in hemolymph or saliva. This result provides the first direct evidence of geminivirus DNA in whitefly vector saliva and establishes a system to further dissect the transmission pathway using a novel *in vitro* approach coupled with molecular detection. In another study, a method was developed for preparing whole whiteflies for immunocytochemistry studies by light or electron microscopy. A detailed functional anatomical interpretation of adult whitefly anatomy was presented. Immunocytochemical studies using antibodies to SqLCV were conducted to localize virus and elucidate aspects of geminivirus-vector interactions, and labeled antibody was detected in most organs and fluids of adult whiteflies. TMoV and cabbage leaf curl geminivirus (CabLCV) coat protein were detected in salivary glands and midgut of the B biotype of *B. tabaci* using immunoflorescence.

Mouthparts and digestive system. The external morphologies of A and B biotype were compared with an emphasis on mouthparts relative to virus-vector transmission. Ultramicroscopic level studies of the anatomy and morphology of the mouthparts, associated organs, and digestive system of the adult whitefly indicate that the mouthparts and gut are somewhat similar to those of aphids. Two mandibular and two maxillary stylets are present, and the food canal is separated from the salivary canal in sections of adult whitefly stylets. The esophagus, filter chamber, midgut, and hindgut are present and the hindgut is lined by a thin layer of squamous-like cells. The accessory and primary salivary glands have been visualized, and are thought to play a role in virus-vector specificity.

Section C. Chemical Control, Biorationals, and Pesticide Application Technology

Compiled by Philip A. Stansly

Saving crops anyway possible from destruction by whitefly was top priority in 1991 when the National Action Plan was in Formation. Naturally, the arsenal of available broad-spectrum insecticides was extensively tested and results reported from 1992 to 1996 in 81 of the 171 abstracts submitted to Section C, "Chemical Control, Biorationals and Application Technology". This provided stopgap controls that brought relief to beleaguered growers and bought time for development and deployment of more effective and selective "biorational" tools, *i.e.* those most compatible with biological control. But hopes for easy solutions sprayed by air die hard, especially when the alternatives may be complex and of uncertain outcome. Meanwhile, effectiveness of the present arsenal of insecticides must be maintained and improved while attempting to limit negative impacts on natural enemies.

Thorough coverage on the underside of foliage where whiteflies reside is necessary for effective use of contact materials. Major improvement through new technologies such as electrostatics have yet to be realized, although high volume air-assisted ground sprayers appear to provide an advantage over hydraulic sprayers and much can be accomplished by proper configuration and calibration of conventional equipment. Decision-making based on scouting is clearly the most efficient way of employing chemical control, especially when backed by action thresholds such as have been determined for cotton and melons. Thresholds must be constantly revised in light of advances in control strategies and advanced to include all crops, including those affected by whitefly-borne viruses. The task of conserving efficacy of existing pesticides requires constant monitoring for early detection of resistance problems in the field and an understanding of genetic, biochemical and ecological mechanisms that lead toward development and spread of resistance in the pest population. Significant advances have been made on these fronts and management schemes based on rotations or mixtures of active ingredients proposed and tested, albeit with mixed results.

Beginning in 1996 Section C action plans have unified objectives for "chemicals" and "biorationals" in the belief that, regardless of the origin of the agent, the rational approach is selective suppression frugally applied to minimize disruption of beneficial fauna. We have yet to truly integrate biological and chemical control, an illusive, and in some minds, impossible goal. The key to success is selectivity in both mode of action and application, combined with sufficient knowledge to successfully manipulate the agroecosystem in favor of natural enemies. Currently, the EPA recognizes two categories of pesticide, synthetic and biopesticide, although the Agency does seem to be moving toward more flexible regulatory requirements based on scientific evaluation of risks and benefits rather than origin of suppressive agents. These are healthy changes that should be encouraged by the research community.

The present status of the struggle with silverleaf whitefly probably is best described as an uneasy truce. Much new ground remains to be covered before declaring a sustainable victory. Nevertheless, chemical control has been contributed significantly to our present ability to at least coexist with the whitefly. It is likely that insecticides will continue to play a key and ever more sophisticated role in whitefly management for the foreseeable future .

Outcomes and Impacts of Research Approaches

C1 *Identification and registration of new chemistry to selectively control SLWF with minimal effects on beneficial organisms.*

Intensive screening of most registered compounds produced a small list of a single chlorinated hydrocarbon and a few pyrethroids and organophosphates (OPs), all showing marginal efficacy. Tank mixes produced some synergism but reduced even further the number of possible rotations. These materials were shown to be highly toxic to aphelinid parasitoids and coccinellid predators although the toxicity of residues is relatively short-lived. Guidelines were outlined for use of detergents and oils in concert with biological control with some degree of success where adequate spray coverage could be obtained. A new class of natural and synthetic insecticides based on sucrose ester chemistry found in cuticular secretions of certain tobacco species was discovered and has proved to be effective against SLWF with no direct impact on hymenopteran parasitoids or coccinellids. The systemic insecticide imidacloprid was put on a fast registration track after spectacular results in the field and has had significant impact on whitefly populations in Florida and elsewhere after receiving federal labels on vegetables and ornamentals. The juvenile hormone analogue pyriproxyfen and the chitin synthesis inhibitor buprofezin were shown to be highly effective against SLWF and relatively innocuous to species of parasitoids tested in the genera *Encarsia* and *Eretmocerus*. A Section 18 emergency exemption was granted in 1996 for use of both these insect growth regulators (IGRs) on cotton in Arizona, and based in part on the favorable results with whitefly parasitoids. The whitefly problem there appears greatly mitigated as a consequence. However, pyriproxyfen has also been shown to be highly persistent in citrus and deleterious to coccinellids, resulting in upsets of homopteran pests such as mealybugs. Therefore, care must be taken when projecting laboratory results on a few species to the field, and the ecological effects of all insecticidal agents should be carefully monitored.

C2 *Relate schedules and methods of applications to thresholds.*

Action/economic thresholds have been developed for melon and cotton yield. Large scale field trials conducted in cotton at sites in California, Arizona, and Texas indicated

that an action threshold between 5 and 10 adults per leaf brought the largest return. Differing results in definition of optimal threshold levels could reflect a number of variables including intensity of infestation, efficacy of control methods employed, sampling system, economic parameters, etc. Sticky cotton has been clearly associated with increasing whitefly populations and whitefly-produced trehalulose and melezitose. However, action thresholds have been difficult to define because of factors such as rainfall which reduces stickiness, variation in numbers of open bolls at times of honeydew production, and the cumulative effects of honeydew deposition on lint quality. Progress is also being made in Florida and California on defining thresholds for irregular ripening of tomato. However, the more elusive goal of decision criteria for whitefly as a virus vector remains largely unresearched.

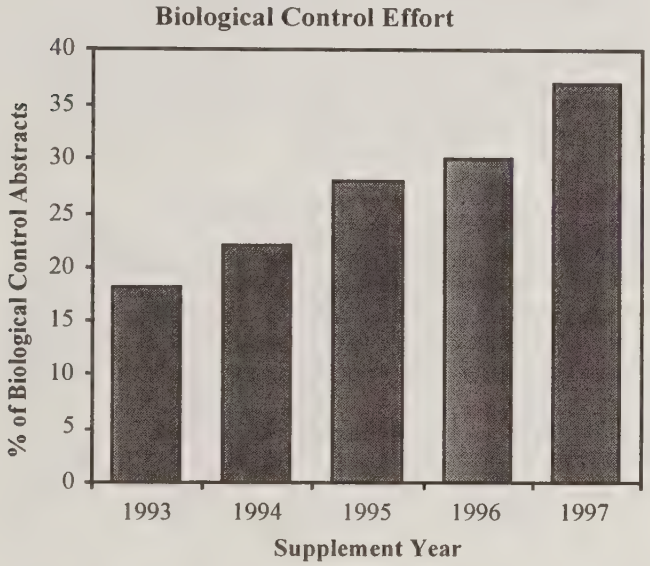
C3 *Elucidate mechanisms, monitor whitefly populations and develop management systems for insecticide resistance.*

Resistance ratios in *B. tabaci* populations on cotton in Guatemala during the mid-1980s were reported in excess of 300 for fenpropathrin and 2000 for deltamethrin, so the ability of *Bemisia* populations to develop resistance to commonly used insecticides was well known before the National Action Plan existed. The whitefly apparently employs a variety of mechanisms to resist insecticidal effects. Target-site insensitivity to OPs has been demonstrated but the effects of synergists also implicate esterase detoxification and oxidative metabolism in resistance to chlorpyrifos and bifenthrin. Furthermore, OPs have been shown to be inhibitors of whitefly esterases which hydrolyze pyrethroids, offering an explanation for the observed synergism between these classes of insecticide. Resistance to fenpropathrin + acephate or fenpropathrin alone have been shown to be quite stable. Cooperative efforts to monitor whitefly resistance began soon after formation of the National Plan, although half of the 28 abstracts in this area were submitted in 1996, reflecting a gradual build-up of activity over the four-year period. Vials, sticky card and leaf disk assays were used, the latter showing greatest discriminatory ability and also greatest correlation with field efficacy. Diagnostic doses have proven more efficient and sensitive than resistance ratios in monitoring changes in sensitivity. High levels of resistance to pyrethroids+organophosphate mixes were reported from Arizona cotton (Maricopa region), to buprofezin imidacloprid in European greenhouses and to buprofezin and pyriproxyfen in Israeli greenhouses. The common thread is that all are closed systems where whiteflies are subjected to continual selection pressure. Except for cases noted above, levels of susceptibility to insecticides of whiteflies in the field decreased moderately, remained stable, or even increased in the case of the Yaqui (Sonora) and Imperial (California) valleys, due apparently to non-exposure of large portions of the whitefly population in soybean and alfalfa respectively. On the other hand, resistance management experiments and/or programs in cotton based solely on rotation of insecticide types in Arizona and Israel have not been entirely successful in reversing trends toward higher levels of resistance, and no more than one application of buprofezin or pyriproxyfen per crop is recommended in Arizona and Israel. Given the apparent mitigating effect of unsprayed refuges to selection for resistance within populations, the positive role of refuges in resistance management should be further investigated.

C4 *Develop improved methods for application or delivery of materials to improve control.*

The objective of successfully targeting spray coverage to the underside of foliage where whiteflies reside was a principal objective of many researchers as evidenced by 27 abstracts submitted over the 4-year period. In terms of impact on both whitefly and parasitoids, coverage was shown to be most critical for oil and soap with physical modes of action than for insecticides with chemotoxic modes of action. Although hopes for a major breakthrough in spray technology have been realized yet, high volumes of air to carry spray material were shown to be beneficial in both air and ground applications. Air application was further improved with the addition of winglets to increase air turbulence. With the aid of a leaf wash method to estimate coverage on individual leaf surfaces, factors such as speed, altitude and drag for air application, nozzle type, pump pressure, spray volume and nozzle configurations were evaluated for particular crops and canopy conditions. Systematic optimization of myriad factors to achieve maximum coverage and, thereby, efficacy of contact insecticides and mycoinsecticides remains a challenge for the future.

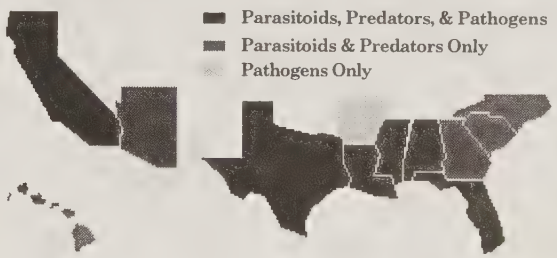
Biological control has served as the focal point in the development and implementation of a management plan for *Bemisia argentifolii* (= *Bemisia tabaci* strain B) infesting U.S. crops. While executing the 5 year National Research and Action plan, biological control comprised 18-37% of the research and implementation activities reported annually as abstracts within the yearly supplements. As suggested by the 20% annual increase in the percentage of biological control abstracts (illustrated in the figure below), many believe that biological control provides the greatest opportunity for delivery of a long-term solution to the whitefly problem across a wide array of cropping systems.



Many aspects of biological control have been studied within the context of the 5-year plan. These include aspects related to control of whitefly populations by *natural control* (the combined action of biotic and abiotic forces in regulating whitefly populations), *conservation* (the manipulation of the environment to favor natural enemies, either by removing or mitigating adverse factors or providing the lacking requisites), *augmentation* (the direct manipulation of parasitoids, predators or pathogens by mass production and periodic colonization), and *importation* (the discovery, importation and establishment of exotic natural enemies for control of an introduced pest). In addition, supporting research in natural enemy biology and systematics has contributed to development of each of the above four biological control components as whitefly management techniques.

While much of the research conducted during the first year of the 5-year plan (40% of the biological control abstracts) examined the role of natural control of whitefly, most researchers quickly discarded the ability of indigenous natural enemies to suppress whitefly populations in favor of augmentative (20-38% of biological control abstracts during the past 5 years) and importation techniques (12-32% of biological control abstracts). Surprisingly, methods for conserving natural enemies (0-14% of biological control abstracts) has received little attention even though these techniques are necessary for the success of any augmentation or importation program. Studies on the basic biology of whitefly natural enemies (10-26% of biological control abstracts) have kept pace with the augmentation and importation research, but natural enemy systematics (0-3% of biological control abstracts) has not. In the sections that follow, we review the advances and shortcomings of each of these five research areas. We conclude this retrospective by evaluating the stimulus provided by the 5-year plan to whitefly biological control research, and by identifying several data gaps that should be addressed in the next 5 years.

Natural Control. Surveys of parasitoids and predators indigenous to the U.S. were conducted in 11 states, whereas only 7 states were surveyed for indigenous pathogens.



Thirteen parasitoid species have been identified from the southeastern states, 8 from Texas, and 3 each from the western states and Hawaii. Ten predator species have been identified from the southeastern and western states, 4 species from Texas, and 3 species from Hawaii. Several surveys have gone beyond simple censusing techniques. The surveys conducted in the desert Southwest have incorporated immunological methods developed by Arizona researchers to assess the proportion of predators within the habitat that have actually fed on *Bemisia*. *Paecilomyces* spp. were noted from surveys conducted in California, Texas, and Florida; whereas *Aschersonia* spp. were located in Louisiana, Arkansas, Mississippi, Alabama, and Florida.

High levels of natural enemy activity were noted from surveys conducted in habitats free from insecticide applications. 90% parasitism on weeds and 92% parasitism on peanuts and soybeans have been reported in Florida. In Texas, 20-82% parasitism and 90% mortality of *Bemisia* larvae have been noted in untreated refuges and adjacent cotton. Naturally occurring epizootics of *Paecilomyces fumosoroseus* have also been discovered in the Rio Grande Valley, TX. In Arizona, 263-1290 parasitoids per minute were collected from unsprayed lantana and hibiscus compared to 0-2 parasitoids per minute regularly collected from sprayed cotton. In the Imperial Valley of California, 30-70% parasitism of *Bemisia* infesting untreated urban ornamentals have been reported. It is interesting to note that few releases of

natural enemies into caged or open environments through importation or augmentation methods have yielded these observed levels of parasitism. With improved management of insecticides, it may be possible to generate these levels of natural enemy activity in targeted cropping systems.

Conservation. Two methods for conserving natural enemies have been examined to date: the identification of insecticides "compatible" with the use of natural enemies and the planting of untreated refuges to enhance agriculturalÊhabitats.

Results from insecticide compatibility tests have been variable, but several general trends have emerged. First, the toxicity of "traditional" chemistries tends to be moderately to highly toxic to natural enemies in the field. Second, the susceptibility of natural enemies varies with life stage. For example, immature parasitoids are less susceptible to insecticides than are adults. Third, susceptibility to insecticides varies with species. Arizona researchers have reported *Eretmocerus* nr. *californicus* and *Chrysoperla carnea* to be less susceptible to insecticides than other species of parasitoids and predators. Fourth, field research conducted in the desert Southwest suggests that toxic effects due to insecticide chemistry are greater than the adverse effects due to application frequency. Finally, *Bt*-cotton has been reported to increase the opportunity for whitefly biological control in Arizona by reducing the numbers of insecticide applications.

Enhancement of natural enemy activity by the development of refuge plantings may be strongly affected by various plant associations. Although California researchers report high levels of parasitism on camphor weed, placement of camphor weed adjacent to melon did not elevate parasitism in the melon. Results from research conducted in Texas suggests that refuge plantings consisting of sunflower, kale and collard may enhance parasitoid activity in adjacent cotton. California researchers, attempting to mimic the work conducted in Texas, increased the numbers of parasitoids in melon adjacent to refuge plantings of sunflower, collard and roselle. Through the use of elemental marking techniques, it was demonstrated that the majority of parasitoids in the California melons originated from the refuges and not from other sources.

Significant progress is still needed in the development of agriculturally feasible conservation methods. Only when these methods are developed may the indigenous fauna function to suppress whitefly populations, and may the natural enemies released through importation and augmentation programs provide the desired levels of control. Without effective conservation techniques, biological whitefly control in annual field crops has little opportunity for long term success.

Augmentation. Augmentation of pathogens, parasitoids, and predators have been attempted in greenhouses and field crops. Regular applications of the fungal pathogen, *Beauvaria bassiana*, have yielded consistent results of 60-95% reduction in whitefly densities in field crops. Researches in Texas and from Mycotech Corporation (Butte, MT) suggest that the variation in population suppression could be reduced with improved application methods. Laboratory evaluations of the fungus *Paecilomyces fumosoroseus* have yielded 57-86% mortality within 5-6 days after application. Increased levels of mortality occur when increased dosages are applied. In addition, *P. fumosoroseus* is reported to repel whitefly adults 4 days after its application to the foliage.

Augmentation of natural enemies into greenhouses has yielded tremendous success. Use of the parasitoid *Encarsia formosa*, which has long been available from commercial insectaries, has been reported to control *Bemisia* infesting poinsettia in Ohio (releasing 2 wasps per plant for 3 weeks) and New York (releasing 3 wasps per plant for 8 weeks when whitefly populations are low). Five weekly releases of 2 adult *Encarsia formosa* (originally collected from the Nile Delta region) per plant also reduced whitefly by 96% on New York poinsettias. While *E. formosa* provides effective whitefly control on poinsettia produced as a Christmas crop, several other species have also been evaluated.

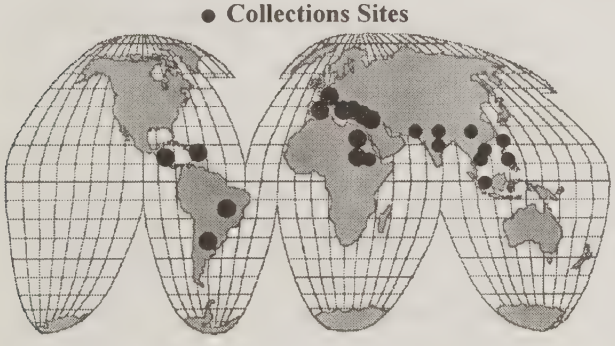
Releases of 3 *Eretmocerus* sp. nr. *californicus* (Arizona) per plant caused 99.1% mortality in New York poinsettia greenhouses. Releases of *Encarsia pergandiella* into tomato greenhouses in France resulted in 92.2% parasitism during the first generations; but the autoparasitic behavior of this species reduced parasitism to 44.1% during the 2nd generations. In California, weekly releases of *Encarsia luteola*, plus 3 weekly releases of *Delphastus catalinae*, at rates of 1 per plant, provided excellent control of *Bemisia* infesting poinsettia, but at a cost 5-times greater than conventional insecticide-based programs.

While augmentation shows potential for field crops, the frequent occurrence of large numbers of migrating whitefly in the desert Southwest have hindered its implementation. In the Imperial Valley of California, 4-5 *D. catalinae* adults released per cotton plant within field cages resulted in a 300% reduction in whitefly densities during the summer crop cycle. However, no suppression of whitefly densities were observed when beetles were released into open field plots. In Arizona, cage trials suggested that releases in excess of 10 *Er.* sp. nr. *californicus* (AZ) per cotton plant may provide adequate control. However, releases made into field grown cotton resulted in only 36% parasitism relative to 30% in no release plots.

Additional hindrances to the adoption of augmentation biological control are the availability of inexpensive natural enemies of sufficiently high quality and the methods necessary for releasing them into large acreages. Development of artificial diets will hopefully reduce the cost of producing natural enemies. USDA-ARS researchers in Arizona have developed a semi-solid artificial diet for *Chrysoperla carnea* that is capable of producing quality natural enemies at a cost savings of $593 per kg of diet. USDA-APHIS researchers in Texas have begun to study the use of banker plants (melon transplants infested with parasitised whitefly) as a method for releasing natural enemies into annual row crops.

Primarily due to the success of augmentation biological control in greenhouses, research conducted during the 5 years covered by the National Research and Action Plan has resulted in a significant expansion in the array of natural enemies available from commercial insectaries. In 1992, only the English strain of *E. formosa* could be purchased by interested growers. Currently, 5 additional species of natural enemies may be obtained from commercial insectaries. In this list are two parasitoids {*E.Êformosa* (Beltsville strain) and *Er.* sp. nr. *californicus* (Arizona strain)}, the predator *Delphastus* sp., and two strains of the fungus *B. bassiana* (Naturalis-L and Mycotrol or Botaniguard).

Importation. In recent years, importation biological control research has dominated biological control research. In support of this research, extensive collections from foreign lands have been made by USDA scientists (collections from 25 countries and 50 host plants yielded 38 arthropod species) and Florida scientists (collections from 7 countries yielded 15 species or populations ofÊparasitoids).



At least three pathogen species, *P. fumosoroseus*, *Verticillium lecanii*, and *Aschersonia* sp. have been collected from whiteflies. While many of these natural enemies have been released into the field, assessment of these releases are still preliminary.

In the San Joaquin Valley, CA, 28 species of aphelinids have been released around private homes. Year round establishment of an *Eretmocerus* sp. from Thirumala, India (M93005) and an *Eretmocerus mundus* from Murcia, Spain (M92014) have reported. In the desert Southwest, reproduction of *Delphastus* sp. was detected 2 months after their areawide release into the Imperial Valley, CA. *Amitus bennetti* was recovered from 2 urban sites and 1 sited adjacent to an agricultural field, and *Encarsia* sp. from India was recovered from 20% of the urban sites after their release into the Imperial Valley, CA. Successful overwintering and dispersal were detected for at least 3 collections of *Eretmocerus* (ERET-1, -3, -10) after 32 parasitoid collections and 1 coccinellid were released in CA and AZ. Thirty parasitoid species or populations have been introduced into the Lower Rio Grande Valley, TX, and 24 parasitoid species / populations have been released into the Wintergarden area of TX. Considering recoveries from these introductions, 3 species or populations of *Eretmocerus* were considered to be the most effective: M92014 (from Spain), M95912 (from Pakistan), and M95014 (from United Arab Emirates). Eight parasitoid populations (1 *Amitus* sp., 3 *Encarsia* spp., and 4 *Eretmocerus* spp.) were recovered 3-4 weeks after their introduction into Florida. One species, *Er.* sp. nr. *mundus*) has been introduced into South Carolina.

Basic Biology and Systematics. The practice of whitefly biological control has been well supported by fundamental research on the biology and systematics of the natural enemies involved. Research on the natural enemy ecology has encompassed a wide array of systems, which includes 29 parasitoids, 16 predators, 8 pathogens, and 17 host plants. To date, 85% of these studies have been conducted in the laboratory. Field studies on the behavioral, population, community, and landscape ecology of whitefly natural enemies are desperately needed.

Considering the limited numbers of abstracts submitted in the area of systematics, one could mistakenly conclude that there has been little effort in this arena. On the contrary, USDA-APHIS scientists have used genetic fingerprinting with randomly amplified polymorphic DNA (RAPD) to identify various natural enemy species and populations. To date, 53 *Encarsia* populations from 18 countries have been divided into 19 RAPD patterns, and 43 *Eretmocerus* populations from 11 countries have been divided into 12 RAPD patterns. In addition, systematics research on *Encarsia* and *Eretmocerus* spp. have been published in the scientific literature, and a taxonomic key to the *Eretmocerus* will be available from Texas A&M University scientists by press time.

Concluding Remarks. The 5-year National Research and Action Plan just completed has acted as a stimulus to the science of biological control as well as its practice in whitefly management programs. During the 5 years prior to the severe outbreaks of *Bemisia* sp. in the U.S., 7% of the 385 *Bemisia* manuscripts published during the period addressed biological control. During the 5-year period after the initial detection but before initiation of the National Research and Action Plan, 8.6% of the 708 of *Bemisia* manuscripts addressed biological control. Since the initiation of the National Research and Action Plan in 1992, 13.3% of the 1420 *Bemisia* manuscripts have addressed various aspects of biological control.

Even with this surge in scientific activity, numerous issues remain a mystery. For example, what role do indigenous predators play in the suppression of whitefly in field crops? Are autoparasitoids detrimental, neutral, or advantageous to whitefly biological control? What are the relative contributions of importation, augmentation, and conservation biological control to whitefly management in ephemeral cropping systems? What utility do pre-release evaluations contribute to successful and economical biological whitefly control? While these questions represent only a sample of many question for which answers are still needed, the information generated during the past five years will provide new insights into the development of predictable and effective biological control of *Bemisia* spp. and other major pests to agriculture.

Since the initiation of the 5-year national research and action plan, much progress has been made in the areas of crop management systems and host plant resistance. Significant accomplishments have been made for all approaches within this section. Research activities were carried out in states across the U.S. and in several other countries. The researched host plants varied and consisted of a diversity of cropping systems. The researched hosts included: alfalfa, citrus, cotton, peanut, soybean, vegetables (broccoli, cantaloupe, collard, lettuce, pepper, squash, sweetpotato, and tomato), weeds, and others. Most of the research efforts were directed toward cotton. Crop manage-ment activities on whitefly populations have included studies on: cropping sequences, irrigation, intercropping, plant nutrients, reflective mulches, and other systems. Host plant resistant research is in various stages of prog-ress for all of the crops. Although breeding for resistance is generally a long term process, which may take several years, plant resistant germplasm has already been released to growers for cotton. The accomplishments for the six research approaches are summarized in the following.

E1 Determine Effect of Traditional Crop Production Inputs on *B. argentifolii* Population Development.

A study was conducted in the southwest in 1992 to examine the effect of melon planting dates and chemical control on whitefly management. All plants died from the overwhelming whitefly infestation. In another study, cantaloupes planted from mid-July to late August did not survive without insecticides. Populations of native parasitoid species persisted in cantaloupe, collard, and tomato treated with foliar imidacloprid, although abundance of the parasitoids was reduced compared with untreated plots. Autumn melon planting in the Imperial Valley since 1992 has been severely reduced. Growers and researchers have had difficulties in obtaining good melon yield even when insecticides were used.

The effect of water stress on whitefly population dynamics was studied in cotton, cantaloupe, and alfalfa. Research shows that water stress may facilitate whitefly infestation. Rainfall and other sources of wetness had a detrimental effect on whiteflies. Local populations declined after intense brief rainfalls, although the decline was less noticeable from sprinkler irrigation. Rainfall dislodged whiteflies from plants and interrupted their feeding and oviposition. In addition, rainfall resulted in a decrease in suitability of the micro environment and improved the conditions for fungal pathogens.

By regulating the distribution or amount of water to cotton plants, whitefly damage was affected. Differences between populations of immature whiteflies on cotton leaves suggest that the insects are attracted to water stressed plants. Fewer *B. argentifolii* were found in cotton with weekly irrigation than in biweekly irrigated cotton. The lowest whitefly populations were observed by integrating the use of reduced water stress by weekly irrigation and conventional insecticides. Oviposition on drought stressed cotton approximately doubled the rate compared with non-stressed plants, managed with furrow or drip irrigation.

Weekly irrigated plants received fewer numbers of whitefly eggs, nymphs, and adults compared with biweekly irrigated plants. Moreover, using action thresholds, weekly irrigated plants required fewer (1-2) insecticide applications to maintain adult whitefly population below treatment thresholds compared with water stressed plants. There was more bloom (8%) in weekly irrigated cotton than in biweekly irrigated cotton, and pink bollworm populations were not affected. Samples of lint from two weekly irrigated cotton cultivars in Arizona had more (46%) reducing sugars than biweekly irrigated cotton. Irrigation also improved cotton fiber quality; namely, the micronaire values were improved. These research studies have consistently shown that water stress management is a useful tool that can be incorporated into integrated pest/crop management programs.

Biochemical regulators were used to mediate interactions between whiteflies and plants on several host plants. Gibberellic acid inhibitors in *Cucurbita pepo* (small sugar pumpkin) resulted in increased chlorophyll content while whitefly-mediated silverleaf reduced chlorophyll content. Chlormequat chloride induced leaf silvering and marginal chlorosis. Plant biochemical regulators-induced leaf silvering and whitefly-induced leaf silvering seem to result from plant hormonal-mediated alterations in growth and development. In related work, an increase in frequency of probing and stylet withdrawal, and a shorter duration of ingestion was seen in plants grown from imidacloprid-treated seeds.

Whiteflies resistant to insecticide were found to have more than the problem of reduced insect mortality. Under laboratory conditions, a highly reproductive whitefly with insecticide resistance was crossed and selected. This was the first experimentation documentation that shows that selection for resistant population of whiteflies can directly affect whitefly reproduction.

E2 Determine Temporal and Spatial Effects of Host Plants on *B. argentifolii* Populations and Dispersion.

Although some crops such as melon, collard, and eggplant serve as excellent host plants for whitefly populations to buildup, others, e.g., pepper and cowpea, serve as marginal hosts and whitefly performance is impeded and populations are slow to establish. Similarly, among germplasms within a given crop, whitefly population increases can vary. Work has been done on identifying overwintering hosts. Stands of wild radish and other weeds, and commercial greenhouses were implicated as sources that sustain populations through winter months and reestablish populations during the spring and summer

months in the southeastern U.S. In the southwestern U.S., *B. argentifolii* was commonly found on various species of weeds (e.g., *Datura* spp., *Malva* spp., and *Abutilon* spp.) during autumn and consistently occurred on citrus during winter. Depending on hosts grown in a given area, a host sequence may consist of spring melon, acala cotton, pima cotton, alfalfa, fall melon, weeds, cole crops, and citrus. The latter three hosts help the whiteflies to bridge the gap from autumn to spring. Melon varieties grown at locations across the U.S., had varying levels of whitefly infestations and varying plant growth and survival. Among groups of *Brassica oleracea*, brussels sprouts, collard, and kale had higher number of adults and nymphs than broccoli, kohlrabi, and cabbage. Leaf area varied considerably among these crops and may be one reason for the different populations. Whitefly eggs, nymphs, and adults are predominantly found on the lowers surfaces of leaves in most crops. However, in peanut, more immatures were found on the upper leaf surface than the lower leaf surface. Within plant and within field distribution of whiteflies and its parasitoids were examined, and will help in evaluating effectiveness of parasitism and other management strategies in the field.

E3 Determine Effects of Colored Mulches, Trap Crops, Intercropping, Row Covers, and Other Innovative Cultural Practices as Potential *B. argentifolii* Control Methods.

Melon, groundcherry, soybean, and squash were investigated as trap crops. In cauliflower, interplanting of melon was useful in reducing whitefly infestation. Melon was also used as a trap crop for cotton, and insecticide treatments were made weekly to directly control the whiteflies and to minimize disruption of natural enemies. However, untreated cotton from this test was unacceptably sticky. Groundcherry was not effective as a trap crop to provide whitefly relief in cotton. In peanut, soybean was used as a trap crop, and there were more whiteflies on soybean than peanut. Some reductions to tomato mottle virus and number of whiteflies were seen in tomato when squash was used as a trap crop, but the results were not consistent.

Yellow, orange, and aluminum colored UV-reflective mulches, and UV-absorbing mulches, were found to be effective for reducing whiteflies and delaying the incidence of tomato mottle geminivirus. In Florida, about 15% of the growers have now adopted the use of silver reflective mulches. One drawback for the silver mulch is the color may be masked and the efficacy reduced when growers frequently apply some fungicides. Also, many growers rely on Admire® to obtain good whitefly control. Reduction in numbers of adult whiteflies and a delay of geminivirus dissemination in tomato were also achieved using living soil covers. Natural germinating weeds, as well as legumes, resulted in few adults and a delay in virus dissemination compared with bare ground or inert soil covers. This work targeted small scale growers (less than five hectares) such as in Central America. Outdoor crop protection by non-woven or spun-bonded polypropylene or polyester sheets over plants were effective, but consideration should be given to temperature buildups and interference with crop pollination. Whitewash sprays and sticky polybutenses sprays reduced whitefly feeding and viruses vectoring; however, there may be phytotoxity concerns with polybutenses. Mid-bed trench row cover treatments resulted in larger melon plants early in the growing season compared with the control and reflective treatments. Whiteflies, leafminers, and thrips were fewer in the row cover treatments than bare grown treatment. On iceberg lettuce, reflective mulches were not efficacious enough to justify their use by growers. Also, repellency from plant extracts (garlic water, and an extract from eucalyptus) and mineral oil sprays did not adequately protect the lettuce from whiteflies.

E4 Develop Reproducible Evaluation Techniques to Isolate Resistance Germplasm.

Many evaluation techniques to isolate whitefly resistant germplasm were explored in several crops. Some techniques were directed toward screening existing cultivars and varieties while others targeted other germplasm sources. The techniques often used multiple tests in either the field, greenhouse, laboratory, or a combination of these environments. Methods were developed to evaluate the following: plant tolerance/ response to insect feeding, feeding and ovipositional selection, the adverse effect of the host on the whitefly, and degree of associated viruses and plant disorder. Data were collected on the number of adults, number of nymphs, number of eggs, adult survival, nymphal survival, nymphal development, plant condition, plant growth, yield, fruit set, degree of stickiness, occurrence of sooty mold, expression of other plant diseases and plant disorders, number of trichomes, leaf thickness, and depth of vascular bundles, and other parameters.

A method was developed for successfully screening tomato germplasm against tomato geminivirus in the greenhouse. In cotton, leaves with reduced trichome numbers, okra leaf shape, red plant color, earliness in fruiting, and leaf thickness have been identified as attributes that relate to resistance to whiteflies. Early maturing fruits may escape plant damage before late-season insect buildups. In cotton, leaf surface pH did not affect host susceptibility. However, leaf thickness was highly correlated with depth of vascular bundles in cotton. A negative correlation was seen between the number of adults on cotton and distance from epidermal leaf tissue layers to phloem tissue, and a positive correlation was seen between the number of adults and thickness of mesophyll tissue layers. The presence of trichomes is generally preferred by whiteflies in cotton, and several other crops, compared with glabrous or a smooth-leaf trait. *Lycopersicon* species were researched based on the trichome type and trichome exudates. Leaf pubescence was a factor in oviposition selection and vertical distribution of oviposition on soybean, although whitefly survival and development were not factors. Conversely, in crops lacking leaf trichomes, such as many cole crops, factors other than trichomes are important in resistance to *B. argentifolii*. Differences in whitefly numbers among cultivars of *Brassica* were associated with color. Red varieties of brussels sprouts and cabbage had a much reduced population of whiteflies compared with other cultivars in their groups. Leaf glossiness contributes to

resistance to whiteflies in collard and broccoli, but the resistance mechanism has not been identified. Host adaptation affected the quality of whiteflies in the laboratory. Whiteflies reared on collard had high performance on collard. Whiteflies reared on a southern pea had a higher reproductive growth rate when transferred to collard than when transferred to southern pea, although they preferred to settle on southern pea. Hence, the host history of experimental whiteflies may affect their performance and behavior, and may result in different conclusions when assessing resistance levels.

E5 Identify Resistant Germplasm to *B. argentifolii* and Associated Viruses and Plant Disorders.

Laboratory, greenhouse, and field studies have been conducted to identify resistant germplasm for several crops. Because some crops, such as tomato and squash, may exhibit symptoms of viruses or plant disorders under relatively low whitefly infestation, it was deemed essential to identify resistance to these conditions and to the insect. Some germplasm entries within a crop had individual plants with a high level of resistance, but entries tended not to have a high uniform level of resistance. Green glaze collard segregated for a glossy and non-glossy type. Glossy types were the most resistant collard entries to whiteflies while most non-glossy types were susceptible. Differences in whitefly colonization preferences were observed among 12 broccoli varieties. Also, among 12 cantaloupes varieties, ovipositional rate, number of nymphs, and adult survivorship in field trials, and greenhouse life tables varied. In an evaluation of squash silverleaf, two zucchini lines (Sunseed 3 and A21-7) had resistance to silverleaf symptoms, but they were not resistance to whitefly infestations. The severity of silvering on these two zucchini breeding lines was not related to the density of immature whiteflies. Conversely, silverleaf severity was linearly related to density of immature whiteflies for four yellow squashes evaluated. No resistance to whitefly was found among squash cultivars in Florida, although parasitism was affected.

E6 Conduct Plant Breeding Studies to Select *B. argentifolii* Resistant Germplasm.

A cotton germplasm line with resistance to whitefly and other good attributes, was developed by USDA-ARS and jointly released with the Texas Agricultural Experiment Station and Rio Farms, Inc. It is commercially marketed as 'Texas 121' and has high yield, early fruiting, and good fiber quality. The first bails harvested in the U.S. in 1995 and 1996 were from Texas 121. Alfalfa germplasm with good whitefly resistance and other good qualities have been selected in California and should be available for seed increase by industry in 1998. Whitefly-resistant F_2 broccoli lines are being back crossed with commercial cultivars to improve agronomic characteristics. Although the glossy characteristic in broccoli imparts resistance to whiteflies, there are also nonglossy germplasm sources that are moderately resistant to whiteflies. Breeding work continues in these and other crops. In general, germplasms have been identified that have some degree of resistance to whiteflies, but most germplasms examined had little or no resistance. New genetic and molecular biology methods along with conventional breeding should accelerate the breeding process.

Section F. Integrated Techniques, Approaches, and Philosphies

Compiled by John Norman, Peter Goodell, Peter Ellsworth, Jon Allen, Carlyle Brewster, and Dennis Kopp

This is a summary report on the progress made during the past five years (1991-1996) on Section F, of the 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Silverleaf Whitefly. This report draws on annual summary reports of this section and others in the 5-Year Plan and the latest knowledge of progress since the annual reports were compiled. The report is divided into individual reports for each of the subsections of section F.

Spatial Analysis and GIS

This part of the program did not get going until about 2.5 years into the project when we realized that to drive spatial models (discussed in F3 below) we needed large scale georeferenced crop system maps. We naturally thought of satellite images for this purpose and this finally lead us to Dr. Jack Paris at CSU Fresno—a remote sensing scientist with 20 years experience in agriculture as well as NASA and the space program. We (scientists from California, Florida and Texas) attended several training workshops at Dr. Paris' laboratory on satellite data analysis and image processing, and have become proficient in this art to the extent that was necessary for making crop system maps out of Landsat scenes. Whitefly-infested agricultural regions—San Joaquin and Imperial Valleys in California and the Lower Rio Grande Valley in Texas—were chosen as obvious problem areas for mapping. On Dr. Paris' advice, and to stay compatible with his laboratory, we obtained a copy of TNTmips™, a $5000 software package for doing satellite image analysis and processing. Although we were instructed in the use of this package by Dr. Paris, the only real way to learn this technology is through a large amount of hands-on experience using the program, which we have now had over the last 2.5 years in the whitefly project. The crop maps that we construct from satellite images are transformed into parameter maps for whitefly, so that we then have spatial maps for reproductive rate, development rates, survival, etc., for whiteflies. These parameter maps are then used directly in our spatial simulations and computer analysis of whitefly problems. The idea of a dynamic, i.e., time varying, parameter map which would result from a dynamic crop system has now lead to the idea of controlling insects by manipulating the whole crop system on a regional basis. We are in the process of developing an analytical approach to this problem using methods from signal processing analogous to designing image or signal filters which interfere with (or filter out) unwanted signals (e.g., whiteflies) and reinforce or amplify desired ones (natural enemies).

These spatial analysis techniques are not confined to simply running a model. One use is to simply predict whitefly fallout patterns resulting from the harvest of highly susceptible host crops (e.g., spring melons) and the subsequent whitefly drift onto target crops (e.g., cotton or alfalfa in summer). Analyzing fallout patterns of whiteflies is the subject of a current grant proposal to USDA NRICGP Entomology Program to check some of our model predictions in the field in Imperial Valley. We calculate the wind drift patterns from a map of melon fields overlaid on a road map, and the resulting map can be used in the field as a reference for collecting samples to check predictions. A second proposal to USDA Southern Region IPM Program will predict and observe the pattern of movement in alfalfa during the summer months.

Modeling

Our intentions were to use the whitefly model to study the area-wide dynamics of these insects. The initial model was therefore formulated as a spatial model using the Beddington et al. (1975) host-parasitoid model to simulate the local dynamics of populations a regional system. The model was grid-based and at that time contained no age-structure for SLW or its natural enemies. Each cell in the spatial grid was homogeneous in some SLW resource and heterogeneity was introduced by varying the host crop assignment throughout the system. To a very large extent the development of the models has paralleled the exponential growth of computer technology over the period of this project.

Initially, (in 1992) the computer code for this model was written using Borland's Turbo Pascal®. In this programming environment, the extent of the grid (spatial environment) and the type of insect dispersal were limited by memory constraints and simulation speed inherent to the programming software. We were only able to simulate spatial systems that contained 64 x 64 grid cells and dispersal had to be local (using rooks, queens and bishops moves). These first models were being run on PC 486 50Mz computers, and our computing power has now increased to 200Mhz Pentium Pro machines which are about 10 times faster.

The early limitations on spatial grid-size and dispersal forced us to spend more time trying to improve our computer code for faster simulation and output display (graphics) than exploring the dynamics of the insects in their spatial environment. On the advice of colleagues in Electrical Engineering who were already familiar with this type of computing problem, we invested in another simulation environment - one that allowed us to concentrate more on biology and dynamics than programming. The new higher level programming environment, MATLAB® from MathWorks, Inc. along with an array of toolboxes (signal processing, image processing, and Simulink) is very efficient with matrix manipulation which is ideal for spatial array modeling.

We were therefore able to add age-structure to the model and along with some unique advances in modeling dispersal with Intergrodifference Equations (IDEs) and Fourier transforms we were now able to solve for insect dispersal and reproduction simultaneously over the entire spatial system in a single calculation. We have since then used the age-structured model with the IDEs to study two

systems. We first used the model to study the dynamics of SLW on an organic farm on Pine Island, FL. The system allowed us to demonstrate the utility of this model approach on a relatively small spatially heterogeneous system. We have also used the model to study SLW dynamics in a large regional system, Imperial Valley, CA which is a prime whitefly problem area in the U.S. Our simulations, agree with that of an earlier model by Wilhoit et al. (1994) indicating that alfalfa is a key problem crop in the valley. Wilhoit predicted a 67% whitefly reduction by alfalfa removal; our model predicts an 85% reduction. We have therefore looked at different scenarios involving alfalfa harvest schedules and found through our simulations that various degrees of synchronized harvest cause a very large reduction of whiteflies. Other possibilities we will examine are 'farming up wind' with whitefly crops, so that the insects will not be able to ride the wind to target crops, but will instead be blown out into the desert or onto bare ground or non-hosts.

Finally, we illustrate below (Figure 1) the effect of synchronized harvest by comparing the last 4 years of a 6-year simulation in which everyone harvests at random versus the case where everyone harvests in a 1-week time window. The complete alfalfa growth period is assumed to be a four week cycle of harvest and regrowth.

Networking

In the original plan, networking focused on the electronic definition. While good progress has been made in this specific area, this report expands the definition to include the wider concept of networking, i.e. *to interact or engage in informal communication with others for mutual assistance or support.* To its credit, the National Whitefly Plan was instrumental in allowing whitefly workers all over the world to develop new connections and contacts. These contacts were achieved through the use of electronic connections, annual conferences, and development of publications. Figure 1 overviews cooperative efforts which have taken place during the five year period of this Plan.

Electronic Connections

Silverleaf whitefly is a widespread problem. For those working with the problem, staying in contact with the most current information is essential. Far flung scientists have made good use of electronic networks to keep informed of recent developments. The INTERNET has played a key role in providing a superstructure for networking. Making use of web sights and home pages, many institutions have created a presence on the INTERNET and provide useful information and resources to users. These contents of these sights vary from research reports to requesting extension information to compilations of whitefly knowledge. Web sites are networking at its best. It is easy to link one site to another, thus entering one whitefly site usually ensures most others will be accessible. The following are useful web sites for SLWF information:

University of Florida - Whitefly Expert
http://www.ifas.ufl.edu/~ent2/wfly/index/html

University of Arizona - Whitefly Research at Maricopa Agricultural Center
http://ag.arizona.edu/AES/mac/whitefly.html

University of California - Kearney Agricultural Center - Whitefly Home Page
http://www.uckac.edu/whitefly/index.htm

University of California - Whitefly Insecticide Bioassay Reports
http://www.ipm.ucdavis.edu/resistance

University of Arizona Whitefly Research
http://gears.tucson.ars.ag.gov/wcrl/wwghome.html

Texas A&M - Cooperative Research on *Bemisia tabaci*
http://rsru2.tamu.edu/bcpru/sweetpot.htm

Purdue University - Cooperative Agriculture Pest Survey & NAPIS
http://ceris.purdue.edu/napis/pests/swf/index.html

Homotpera Newsgroup
sci.bio.entomology.homoptera

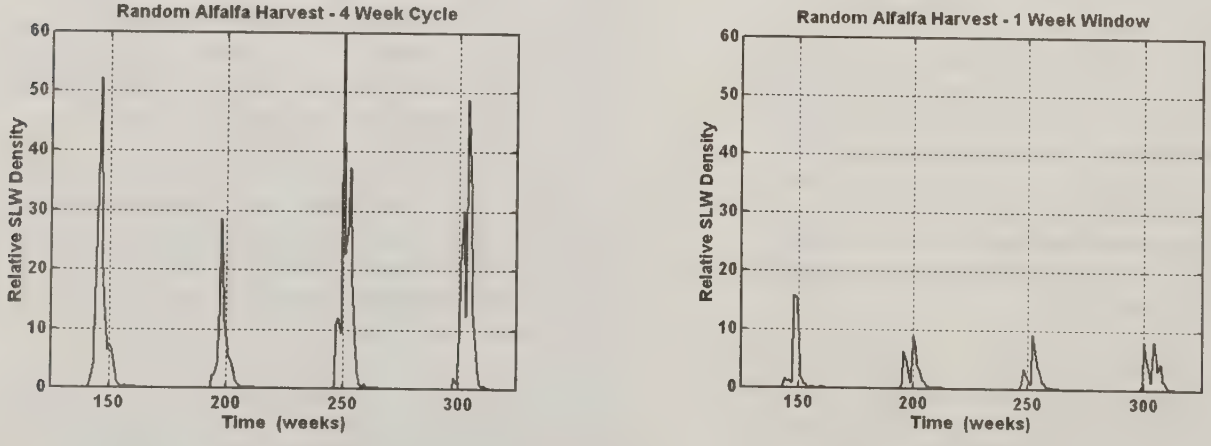


Figure 1. A four-year simulation of silverleaf whitefly (SLW) in Imperial Valley, CA. (Left) - Completely random alfalfa harvest showing variation from year to year due to wind variation. (Right) - situation where farmers synchronize their harvest into a one week time window. Whitefly is reduced 80-90%. Similar reductions can be obtained for 2-week harvest windows as well.

Other valuable electronic networking tools are list servers. These are mailing lists developed around specific topics, such as whitefly. They function as a bulletin board but deliver to your e-mail address rather than a public area on a computer. List servers can be valuable for general discussion and situation updates. Subscription instructions to the whitefly list server are available at the Kearney Agricultural Center (*http://www.uckac.edu/whitefly/index.htm*).

Meetings

If electronic resources help sustain contacts, meetings are where they are born. Perhaps the most overlooked networking success is the most obvious, The National Whitefly Plan and its annual meeting. Here current information is brought together in one place and shared among the interested workers. The abstracts are gathered and provided to the community at large, thus making the state of whitefly knowledge available to a wide audience.

The annual meetings have facilitated new interactions in research and extension activities. It has created a new synergism by developing new contacts and networks. These meetings are often the spring board to other opportunities such as the 1995 International *Bemisia* Symposium in Israel was attended by many of whitefly experts from the U.S. Closer to home, professional societies have provided the opportunity for meetings. For example, the Beltwide Cotton Production Conferences have had sessions dedicated to whitefly topics since 1992. The Entomological Society of America has a separate symposium on the challenges of whitefly biological control.

Publications

The publications mentioned in a previous section are excellent examples of networking opportunities. These regional publications allowed a large number of whitefly experts to pool their knowledge and resources. The resulting publications were produced faster and with deeper knowledge than any individual could have done. The bibliography of developed by the USDA/ARS Western Cotton Lab is an invaluable tool. It was made available as part of the National Whitefly Plan Publication as well as through the web site (*http://gears.tucson.ars.ag.gov/wcrl/wwghome.html*).

An electronic form of a group publication is the Whitefly Knowledge Base developed by Dr. John Fasulo of University of Florida. This computer program collected available information from experts from around the country and brought it together in an easy to use reference. The stand alone program was distributed to over 50 people. It is also available as an INTERNET web site as well (*http://www.ifas.ufl.edu/~ent2/wfly/index.html).*
The extension network which developed in the southwest provided the San Joaquin Valley a leg up on the pest after it became introduced in 1992. The research and extension publications from Arizona provided the foundation of the whitefly management in this area. This area's rapid advance in managing this pest would have been impossible without close cooperation and communication with colleagues from Imperial Valley, Arizona, and Texas.

Organizational Networking

Within the southwest, several organizational networks developed. The Southwest Whitefly Resistance Management Group strives to coordinate information and experience. This group developed a general consensus to managing this pest with each region developing specific guidelines. These guidelines were published annually as Whitefly Management in Cotton between 1994 and 1996 through the sponsorship of Cotton Incorporated.

Community networks describe in earlier sections are essential in developing regional management approaches to this pest. Ideas borrowed from the Imperial County Whitefly Management Committee were incorporated in the San Joaquin Valley's management group. The Imperial Valley group was recognized for its efforts by CA Department of Pesticide Regulation with an IPM Innovator Award.

Integrated Extension

The 5 Year Plan suggested several areas of work which needed to be accomplished with the Integrated Extension delivery system. The plan's primary goals were to reduce pesticide use and improve resistance management for whiteflies, provide a long host-free period, determine crop sequencing patterns which would reduce host availability, timely weed and old crop destruction and other such cultural management practices which would delay the onset of major whitefly infestations and contribute to the success of other management techniques, and encourage field scouting/monitoring to provide a more accurate assessment of whitefly infestations and the need for any artificial control measures.

Some of the very first work conducted to implement the plan was to organize growers, commodity organizations, other private citizens, research (university, USDA-ARS and USDA-Aphis) and extension personnel into task forces to pool knowledge on whitefly activities and knowledge bases, and to begin to implement areawide approaches to the management of whiteflies. Successful taskforce operations were conducted in Texas, Arizona and California by the early stages of the plan. The combined efforts of the various members of the taskforces were able to appeal to area growers in achieving reduced whitefly infestations and consequential reductions in insecticide usage for whiteflies.

All of the taskforces approached the management of whiteflies in an integrated approach, even though each operated to fit the parameters of their own unique areas of whitefly infestation. There was recognized a need to avoid trying to manage whiteflies with a single approach such as insecticides. Experience in the very first year of severe infestations proved that insecticides alone would not adequately control whiteflies. Thus, additional management approaches, such as crop destruction, planting early to avoid high levels of whiteflies later in the season, delaying planting new whitefly susceptable crops following a period when another host crop was grown to avoid high levels of whiteflies coming from old crops,

using treatment thresholds to prevent over use of insecticides, avoiding use of broad spectrum insecticides early in the season to aid in the preservation of natural enemies of whiteflies, and using resistant or tolerant varieties where they exist to reduce potential damage by whiteflies and thus further reduce the need for insecticides, were incorporated into overall IPM schemes.

Actual field implementation of the integrated approach to whitefly management was well documented in the Texas Lower Rio Grande Valley area in 1991 and 1992, and the Arizona cotton production region starting in 1994. Grower-community citizen meetings were conducted by the Cooperative Extension Service to provide opportunities for the two groups to share ideas and concerns about whiteflies in their respective areas. From these meetings, growers and citizens where able to learn more about whiteflies and to learn how each others domiciles were impacting whitefly infestations and management.

In the Lower Rio Grande Valley of Texas, growers, Texas A&M University researchers and Extension personnel and USDA-ARS and USDA-Aphis researchers, and commodity organization leadership formed a taskforce to evaluate the events and circumstances which led to the SLWF infestations and damage and to implement appropriate actions to alleviate the problem. The first and most important action taken was the recognition that SLWF was a multi-crop, multi-season pest which could not be managed in one crop only, nor with just insecticides alone. All growers in the LRGV had to take action on all of their crops in order to prevent the heavy and widespread infestations which led to the disastrous crops damage in the initial stages of SLWF invasion. Secondly, and perhaps most important, was the changing of cultural practices which had increased the SLWF population levels in the LRGV. Widespread encouragement through newsletters, personal contacts, newspaper stories, radio promotions and agricultural grower meetings were implemented to achieve quick crop residue destruction following harvests of all SLWF hosts grown commercially in the LRGV.

A pest management task force consisting of University of Arizona extension personnel and local growers and pest control advisors (PCAs) was formed in the Laveen-Tolleson community of central Arizona in 1993. This program led to better cooperation and coordination of pest management activities among growers in this 128 square mile area west of Phoenix. From 1993 through 1995, regular meetings were held with growers, PCAs and program personnel, whitefly management practices were reviewed and community action was planned and implemented. Written works targeted group communication, education and information update and included over 20 newsletters, community data updates, bulletins and fact sheets. In 1994 whitefly sampling procedures were implemented and demonstrated in 8,000 acres of cotton. This community-wide sampling project, in turn, provided a forum for operational testing of a whitefly sampling protocol which has become widely used in Arizona, northern Mexico, and California. In 1995, growers formed their own pest control district targeting whiteflies and other pests and hired a manager and other personnel to sample whiteflies and coordinate pest management activities in over 14,000 acres of cotton. Whiteflies were also sampled in 6 watermelon fields within the district that year. Furthermore, another group of cotton growers and PCAs near Gila Bend Arizona initiated a community pest management program targeting *Bemisia* and pink bollworm and used techniques tested in the Laveen-Tolleson program. In 1996, all cotton in this community program were sampled for whiteflies, fields were treated based on recommended thresholds, a recommended integrated resistance management plan was used, and whitefly numbers were successfully managed with as little as one insecticide application (in 1995 up to 12 were required).

A "Train the Trainer" series was conducted in California to provide whitefly management educational information to many more educators so that grower and private communities could make more informed decisions regarding whitefly management on their farms and around their homes. Private citizen volunteers were trained to answer calls and other inquiries as to best serve citizens with whitefly concerns and questions. This program was modified and used in Arizona as well.

Publications of various forms designed for grower use have been one of several positive outcomes of the National 5 Year Silverleaf Whitefly Plan. These publications include information ranging from the differences in identification of Silverleaf whiteflies from other whiteflies to research-proven, regionalized whitefly management practices which growers can put to immediate use on their farms. These include:

Booklets:
- Management of Silverleaf Whitefly: A Comprehensive Manual on the Biology, Economic Impact and Control Tactics (TAMU)
- Managing the Sweetpotato Whitefly in the Lower Rio Grande Valley of Texas", "The 1996 Whitefly Resistance Management Program for Arizona Cotton (UA)
- Whiteflies in California, A Resource for Cooperative Extension

Leaflets:
- Sampling Sweetpotato whitefly nymphs in cotton (UA)
- Whitefly Management in Arizona Cotton 1996 (UA)
- The 1996 Whitefly Resistance Management Program for Arizona Cotton (UA)
- Sampling Sweetpotato Whitefly Adults in cotton (UA)
- A New Whitefly in Garden and Farms (UC)
- The Silverleaf Whitefly (UC)

Slide sets:
- Slide to accompany Whiteflies in California, A Resource for Cooperative Extension (UC)

III. Research Abstracts for 1997

Reports of Research Progress
Section A. Ecology, Population Dynamics, and Dispersal
Co-Chairs: Larry Godfrey and David Byrne

Investigator's Name(s): D. Bivins, P. C. Ellsworth, P. Brown, R. F. Chapman.

Affiliation & Location: University of Arizona, Maricopa Agricultural Center, Maricopa, AZ; Department of Entomology, Tucson, AZ.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1995-96.

Overwintering Ecology of *Bemisia*

Laboratory and field studies were conducted on *Bemisia* cold tolerance and overwintering population dynamics. Whitefly adults were found to be freezing intolerant. Supercooling points were consistently low, ranging from 24.11 to -26.41˚C. No differences in supercooling points were found between genders or among whiteflies reared on lantana, broccoli and cheeseweed. Influence of duration of exposure to cold temperatures on whitefly survival was also examined in laboratory studies. Less than 10% of whiteflies survived when exposed to -9˚C for 1 hour and none survived at this temperature when exposed for 2 or more hours. Further, only 2% of whiteflies survived when exposed to a temperature of -6˚C for 3 or 4 hours. A three-dimensional logistic surface model is being constructed for predicting probabilities of adult whitefly survival as a function of low temperature and duration of exposure. Whitefly cohorts were followed during the winter months of 1995 and 1996 on four plant species at multiple field locations in Arizona. Weather stations were present at each of these sites. These data on whitefly overwintering populations are currently being analyzed. Information from laboratory and field experiments are being incorporated with weather data from stations throughout Arizona toward a model of *Bemisia* overwintering dynamics.

Investigator's Name(s): Steve Castle and Tom Henneberry.

Affiliation & Location: USDA-ARS, Western Cotton Research Laboratory, Brawley, CA and Phoenix, AZ.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1996.

Progeny Sex Ratios and Production by Wild-Type Single Pairs

Information on *B. tabaci* population structure and dynamics is still quite limited. In common with other agricultural pests such as spider mites and phytophagous thrips, *B. tabaci* is a haplodiploid organism. Sex determination is arrhenotokous, with unfertilized eggs developing parthenogenetically into males and fertilized eggs developing into females. This mode of sex determination often yields biased sex ratios favoring one or the other sex depending on a range of conditions. To determine the pattern for *B. tabaci,* progeny sex ratios from single pair matings were studied in a greenhouse using field collected parents. Single males and females were randomly paired within an 8 cm^2 clip cage attached to whitefly-free cantaloupe plants. A cohort of 36 pairs were followed over a 24 day period. Serial tranfers of the parental pairs were carried out on six different leaves per pair. The duration on each leaf from the first to last interval was three, three, three, four, four, and seven days, respectively. Once attached, clip cages remained in position on leaves through courtship and copulation, egg laying and hatching, immature development and emergence of the next adult generation.

Losses of the male or female parent in some of the starting 36 pairs resulted in broods classified into three groups: A) those whose parents remained alive and intact throughout the 24 day mating and oviposition period; B) those whose mothers or C) fathers escaped or did not survive until day 24. The eleven pairs in group A that remained intact for the 24 day duration produced progeny sex ratios mostly biased toward higher female proportions. Eight of the eleven pairs produced total brood female proportions ranging from 0.59 to 0.77, while the other three pairs produced sex ratios near parity. Five of the eleven pairs produced total adult progeny that exceeded 500, and all but one pair had total adult progeny in excess of 400.

The highest number of progeny produced was 608 by a female in group C. For others in this group, progeny produced during intervals in which the male had been present had a higher female proportion for eight of ten pairs (0.58 to 0.82), while two of the ten gave female proportions of 0.52 and 0.55. Once the parental male was lost, the conversion to mostly male or all male progeny was usually fast, indicating that females continue to be inseminated throughout their lives if they are producing female progeny.

The mean number of male and female progeny per female per day was determined for the eleven pair in group A that remained intact for the entire 24 day period. Beginning day 5 through day 20 of the 30 day emergence period, numbers of female progeny consistently exceeded male progeny, on some days by ratios of 2:1 or greater. Only at the beginning and end of the emergence period were male and female proportions near parity. The mean number of total progeny per female per day exceeded 20 on 15 of the 30 day emergence period. Based on these daily per capita progeny production data, estimates of r, the intrinsic rate of increase, were obtained. Two different methods to estimate r were used, each one giving almost identical r values. The average r calculated from the data for the eleven pair in group A was 0.228, with a range of 0.220 to 0.237 for individual females.

Investigator's Name(s): G. DeGrandi-Hoffman[1], S. E. Naranjo[1], and J. Gould[2].

Affiliation & Location: [1]Western Cotton Research Laboratory, USDA-ARS, 4135 E. Broadway Road, Phoenix, AZ 85040; [2]APHIS-PPQ Methods Development, 4135 E. Broadway Road, Phoenix, AZ 85040.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1996.

Insights on *Bemisia* Population Dynamics from Simulations with the BIOCONTROL-WHITEFLY Model

A temperature-based mathematical model that simulates *Bemisia* biotype B (= *B. argentifolii* Bellows and Perring), parasite, and predator population dynamics (BIOCONTROL-WHITEFLY) has been developed. The model, called BIOCONTROL-WHITEFLY, also simulates pesticide applications and augmentative releases of parasites and predators and their effects on *Bemisia* populations. Predictions from BIOCONTROL-WHITEFLY on *Bemisia* development and population growth at various temperatures on cotton are comparable with literature values. The model predicts that temperature and migration are the most important factors influencing *Bemisia* population growth and the potential efficacy of biological control agents. Simulations indicated that *Bemisia* populations could be significantly impacted by a parasite with host feeding behavior if immigration did not occur. Simulations were conducted to determine the effectiveness of augmentative releases of biocontrol agents and pesticide applications in reducing *Bemisia* populations when immigration occurred (immigration rate = 2.5 whitefly females per leaf per week). The pesticide application was more effective in reducing the *Bemisia* population in the short term compared with the augmentative release of host feeding parasites. However, in the long run neither control strategy resulted in a permanent reduction of the *Bemisia* population when immigration occurred.

Investigator's Name(s): H. M. Flint, D. Hendrix, M. Salvucci, and S. Crafts-Brandner.

Affiliation & Location: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ 85040.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1995 and 1996 Seasons.

The Effects of Daily Removal of Cotton Blooms on Plant Growth and Infestations of the Silverleaf Whitefly

Cotton, Deltapine 5415, was planted in small field plots at the University of Arizona, Maricopa Agricultural Center (MAC) Farm, Maricopa, Arizona. In 1995, three treatments were initiated when plants began blooming: 1) blooms counted and removed daily throughout the season (Picked), 2) blooms counted and each gently pinched daily (Pinched), and 3) blooms counted daily (Untreated). In 1996, blooms were counted and removed (Picked) or counted only (Untreated) in plots that were irrigated either weekly or biweekly. Individual materials and methods for all the tests conducted in 1995-96 can only be briefly summarized.

1995. Plants with blooms removed produced 2.0 times as many blooms as untreated plants and were 11% taller than untreated plants or plants in which blooms were pinched (Pinching blooms had no effect on any of our measurements). Leaf water potentials were not different between treatments on any of six test dates. Measurements of fifth mainstem node leaves on 13 September indicated no significant differences in leaf thickness. Considerable variation within and between treatments occurred in levels of glucose, fructose, and sucrose in leaf disks from fifth mainstem node leaves on five sample dates. No consistent differences in leaf sugar content were found between leaf samples of plants with blooms removed and untreated plants. Further, there were no significant differences on five sample dates in soluble proteins, chlorophyll, or amino acids in leaf disks from leaves of picked or untreated plants. In July, there were no differences in whitefly infestations but in August, there were significantly 34 and 38% fewer eggs and nymphs, respectively, on plants with blooms picked, than on untreated plants. In September there were 34 and 50% fewer eggs and nymphs, respectively, on plants with blooms picked. Two counts of adults in late August indicated 73% as many adults on fifth mainstem-node leaves of plants with blooms picked than on untreated plants.

1996. Plants with blooms picked produced 2.8 times as many blooms as untreated plants, but there were no differences in blooming due to weekly or biweekly irrigation. Plants with blooms picked were 23% taller than untreated plants but irrigation had no effect on plant height. There were significant reductions in leaf water potential in weekly compared to biweekly irrigated plants on four sample dates but no differences were found between picked and untreated plants. Whole plant dry weights (leaves, stems, fruit) were not significantly different for any of the treatments on three sample dates. Defruited plants maintained equivalent weight throughout the season, regardless of irrigation, by producing additional stem and leaf weight (larger plants) compared to untreated plants. For example, dry leaf weight on 23 Aug. was 60% greater for plants with blooms picked compared to untreated plants. By early September, the specific leaf weight (gram dry leaf weight/m^2) was 18% greater for plants with blooms picked than untreated plants (irrigation had no significant effect). Season total whitefly eggs were significantly reduced 41% for weekly compared to biweekly irrigation and 31% for plants with blooms picked compared to untreated. Similarly, nymphs were reduced 36% and 30% by weekly irrigation and blooms picked, respectively. These reductions in eggs and nymphs were due to reduced numbers of adults on leaves: 59% as many adults per fifth mainstem node leaf for weekly compared to biweekly irrigation and 75% as many adults for plants with blooms picked compared to untreated. The reasons for reductions in whitefly infestations on plants with blooms removed remain undetermined.

Investigator's Name(s): L. D. Godfrey[1], J. P. Wood[2], P. B. Goodell[3], and J. Eckert[3].

Affiliation & Location: [1]Department of Entomology, University of California, Davis, CA; [2]Department of Entomology, University of California-Davis, U.C. Cotton Research Station, Shafter, CA; [3]Statewide IPM Project, University of California, Kearney Agricultural Center, Parlier, CA.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1996.

Spatial and Temporal Distribution of the Silverleaf Whitefly in the San Joaquin Valley

The silverleaf whitefly (SLWF) was first found in the San Joaquin Valley, in some cotton fields near Bakersfield, in 1992. Since then it has expanded throughout the Valley usually at low to moderate levels but occasionally at levels high enough to cause economic damage. This study looked at whitefly population growth from 1994 through 1996 using three by three inch yellow sticky cards along four east-west valley transects. Three trap lines were in Kern County (south, central, and north) and one line cut across Tulare, Kings and Fresno Counties (central valley). Sticky traps were placed every two miles and every one mile along the Kern Co. and central valley transects, respectively. All sticky traps were left out for a period of 24 hours, collected, and then the number of SLWF adults were counted under 50X magnification and recorded.

SLWF populations in the San Joaquin Valley were higher and more widespread in 1996 than in the previous two years. In most of the areas sampled by the sticky traps, 1996 SLWF counts were equal to or higher than 1994 and much higher than in 1995. The only trap line that had a higher average count in a year other than 1996 was the central Kern Co. trap line in 1994. This area had high 1994 mean sticky trap counts that were in part due to just a couple of severely infested spring melon and cotton fields. The two northern lines that had especially high SLWF counts in 1996 compared to the previous two years. The central valley transect had a 1996 peak count of 409.2 SLWF/sticky trap which was over 10 times greater than the previous high of 39.6 SLWF/sticky trap in 1994. Also, the northern Kern Co. trap line 1996 peak count of 241.0 SLWF/sticky trap was over six times greater than the previous high of 37.2 SLWF/sticky trap from 1994. The highest number of SLWF/sticky trap from all three years was from the 1996 southern Kern Co. transect. SLWF were especially heavy in the central part of the trap line in an area dominated by spring melons and cotton, especially pima. This trap line was only sampled in 1996. but our observations during previous research have seen the SLWF populations in this area go from low levels in 1994, to moderate levels in 1995 to the moderately high levels we saw in 1996.

The differences in SLWF population from 1994 through 1996 appears to be related in part to winter and spring environmental conditions. In 1995 there was a harsh winter and a cool wet, spring that resulted in significantly lower degree day accumulation and the two to four week delay of the planting of key SLWF host crops such as spring melons and cotton. The spring and summer of 1996 were conducive to rapid SLWF population growth. Another factor contributing to the low 1995 SLWF numbers could have been the influence of high numbers of other cotton pests (spider mites, lygus bugs, and cotton aphids). The frequent insecticide treatments for these pests and also direct competition for leaf tissue may have had an influence on SLWF numbers. One of the factors in individual field population levels appears to be the proximity to potential overwintering hosts. Early SLWF finds on the sticky traps frequently came from traps that were near overwintering sites such as citrus orchards and urban areas.

Investigator's Name(s): T. J. Henneberry[1], B. Blackledge[1], H. H. Perkins, Jr.[2], D. L. Hendrix[1], R. L. Nichols[3], and Terry Steele[1].

Affiliation & Location: [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ; [2]USDA-ARS, CQRS, Clemson, SC; and [3]Cotton Incorporated, Raleigh, NC.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: January 1, 1995 - December 30, 1996.

Reducing Cotton Lint Stickiness

Cotton stickiness has become a more pressing problem with increasing whitefly, *Bemisia* spp., populations. Laboratory and field studies were conducted to evaluate the potential of an experimental enzyme for degrading honeydew sugars in cotton lint and reducing cotton lint stickiness (thermodetector counts). In the laboratory, thermodetector counts decreased with increasing moisture percentages. Reduced counts occurred more rapidly when 1% of a proprietary enzyme was included in water solutions and seed cotton moisture percentages were 11% or higher. Higher reductions in thermodetector counts occurred following incubation periods of 14 or more days as compared with 1 or 3 day incubation periods. In the field, spray nozzles mounted in a spindle picker intake duct were more effective for application of water or water plus enzyme solutions than nozzles on a modified spray boom mounted in front of the picker. Water plus 1% enzyme applied to seed cotton during harvest significantly reduced thermodetector lint stickiness of seed cotton samples taken from a cotton module before ginning and for lint samples after ginning compared with water-treated seed cotton. Heavy rains, in one experiment, increased seed cotton moisture in the modules to 17.9 and 20.8% for water-alone and water plus enzyme-treated cotton, respectively. Modules heated to maximum temperatures of 160°F (water) and 163°F (water plus enzyme), respectively on day 9 following cotton harvest and module building. Temperatures for the water plus enzyme-treated seed cotton were significantly higher than for the seed cotton temperatures in the module built with water-treated seed cotton. In another experiment, harvested untreated control seed cotton in a module averaged 7.4% moisture compared to 10.9% for seed cotton in a module built from water plus enzyme-treated seed cotton. Average temperatures of the seed cottons at module building time were 87° and 83°F for the untreated and water plus enzyme-treated cotton, respectively. Three days after module building, average temperature for the seed cotton in the control module was 88°F compared with 114°F in the water plus enzyme-treated module. Thermodetector counts were significantly reduced by the water plus enzyme-treatment compared to untreated seed cotton.

Lower thermodetector counts for untreated cotton, water-treated, or water plus 1% enzyme B-treated cottons following commercial ginning suggested that gin processing reduced cotton stickiness. Preliminary results with simulated spindle picker processing of moderately-sticky but not light-sticky cotton showed increased thermodetector counts when spindle moisture pads were operated. Ginning effects were minimal but reduced amounts of trehalulose and reduced thermodetector counts occurred following each lint process. Leaf trash from ginned seed cotton contained trehalulose and melezitose.

Investigator's Name(s): Rufus Isaacs and David N. Byrne.

Affiliation & Location: Department of Entomology, University of Arizona, Tucson, AZ.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: January 1996 - December 1996.

Host Location Flight Behavior of *Bemisia*

In the past, models of whitefly dispersal, flight behavior and host selection in the field were founded on an assumption that these insects are weak fliers. Whiteflies were thought to be carried on the wind and then to land on plants at random and make decisions about remaining or leaving after assessing host suitability. In addition, there has been an incomplete understanding of the role of environmental conditions in promoting or inhibiting take-off. We have started a project to investigate the host-location flight behaviors of the sweet potato whitefly, *Bemisia tabaci.* Our observations during fieldwork at the Yuma and Maricopa Agricultural Centers led us to predict that windspeed would be a major factor in the determination of take-off activity in this insect. We also predicted that *B. tabaci* would have some capacity for upwind, oriented flight to host plants.

A horizontal wind-tunnel (1 x 1 x 1.5 m) was constructed in our laboratory, equipped with a video recording system for the study of whitefly flight. We first tested the hypothesis that take-off by *B. tabaci* is influenced by windspeed. Groups of 10 insects were assayed for their takeoff behavior over 15 minutes in windspeeds ranging from 0 to 35 cm/s (0 to 0.8 m/h). We found that takeoff was inhibited by even these slow air velocities. Addition of a visual cue to the test arena (projected onto the upwind end of the tunnel) increased take-off behavior at the intermediate windspeeds tested (10 and 20 cm/s), demonstrating that external stimuli have a role in the flight behavior of *B. tabaci.*

Experiments were also conducted to determine the capacity of *B. tabaci* for upwind flight, and the influence of visual stimuli on this behavior. Individual adult *B. tabaci* were released in the flight chamber with windspeeds set at 0, 15 and 30 cm/s, with either no visual stimulus or a green 550 nm monochromatic target. When the visual stimulus was not present, insects remained aloft but were carried down the tunnel on the air. As the airspeed increased, the whiteflies were blown faster on the air. In contrast, when the visual stimulus was present, insects made upwind flights to the visual stimulus and landed on it, even at the highest windspeed.

These experiments have shown that the flight behaviors of *B. tabaci* are affected by environmental conditions and visual stimuli. The ability of this insect to fly upwind towards attractive stimuli is greater than previously thought, and we are continuing to investigate the factors that influence host location flight behaviors in *B. tabaci.*

Investigator's Name(s): Joseph E. Leggett and LeAnne Elhoff.

Affiliation & Location: USDA-ARS-PWA, Western Cotton Research Laboratory, Phoenix, AZ 85040-8830.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: Past Field Season.

The Use of Suction Traps to Sample Whitefly Populations

The use of yellow sticky cards to estimate field populations of adult whiteflies has been a futile endeavor. Therefore, a motorized whitefly trap was tested to determine if cotton field sampling efficiency and predictability could be improved for adult whiteflies *Bemisia argentifolii* Bellows and Perring. The motor (Mabuchi cermag motor RE280, 3 v, 7800 rpm) operated whitefly trap basically consisted of a 5.3 cm ID cylinder 8.7 cm long enclosing a 5 cm fan. The bottom of the trap was 17 cm above the soil surface, and mounted on a 3 mm diameter steel rod to facilitate orientation with wind direction. Power was supplied by four size AA alkaline batteries. A polyester bag (13 x 19 cm) was tied around one end of the cylinder. Whiteflies were attracted to the trap by yellow painted on the "tail-like" end of the trap and blown into the bag by the fan, which killed but didn't mutilate the adults.

The suction traps were initially tested in the cotton field west of the Western Cotton Research Laboratory (WCRL) for 7 dates from 30 July to 22 August 1996 where adults averaged less than one per leaf. The traps were tested for 4 dates from 27 August to 18 September in fields with more than 5 adults per leaf at Maricopa Agricultural Center. A treatment site consisted of one suction trap 5 meters into the cotton field and one trap on the outside edge of the field. For comparison, yellow sticky cards (7.6 x 12.7 cm) were placed on the ground 5 m to right and left of each suction trap. There were four replicates of a trap site configuration with 100 m between sites for each test date. The tests began between 6 to 7 am and at hourly intervals, the bags on the suction traps were changed, the yellow cards were replaced, and 10 3rd or 4th main stem node leaves were turned to record adults per leaf at each trap site. After 3 hours of collecting data the traps were removed and the yellow cards and bags from the suction traps were returned to the laboratory for counting and recording. For each test day, 10 leaves from the 3rd, 4th, or 5th nodes were picked for each replicate to count and record whitefly nymphs.

There were no significant differences in number of adult whiteflies captured among the three time periods and captures over time for each date were averaged for each trap. The capture of adult whiteflies per hour in suction traps located in the cotton fields compared with adults per leaf turn had the highest coefficient of determination at $r^2 = 0.86$ ($F = 316.5$, $P \leq 0.01$, $df = 1,49$). The comparison of adults per hour on sticky yellow cards in the cotton fields and adults per leaf turn produced an r^2 of 0.50. The comparison of adult whiteflies captured in suction traps located inside and outside the cotton fields resulted in an r^2 of 0.42 and comparison of sticky yellow cards located inside and outside the cotton fields resulted in an r^2 of 0.25.

In preliminary test where capture of adult whiteflies were recorded from 6 am to 12 noon, the number of adults captured per hour began to decrease after 9:00 am. In a combination of suction traps and sticky yellow cards, the mean numbers of adult whiteflies captured per hour ending at 7, 8, 9, 10, 11, and 12 am were 43.1, 46.1, 57.7, 12.3, 6.4, and 2.0. This data was collected on 25 June and 8 July 1996.

Investigator's Name(s): Steven E. Naranjo[1], Peter C. Ellsworth[2], and Jonathan W. Diehl[2].

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: June 1996 - September 1996.

Partial Life Table Studies of *Bemisia* in Cotton Fields Subject to Different Management Strategies

A large-scale (» 80 hectares), multi-institutional (UA, ARS-Phoenix, ARS-College Station) experimental study was initiated in 1996 to examine and demonstrate strategies for *Bemisia* management involving the use of two insect growth regulators (IGR) granted section 18 status in Arizona. The study involved three different insecticide regimes (buprofezin followed by pyriproxyfen, pyriproxyfen followed by buprofezin, and a rotation of conventional materials), three action threshold levels for initiating insecticide treatments, and application by either air or ground equipment. Individual plots were 1.6 hectares.

As part of this research project, comparative partial life table studies were conducted in plots treated with either conventional insecticides or one of the two IGRs. Cohorts of eggs and settled 1st instar nymphs were established from natural populations in late July (3 plots) and again in mid August (3 plots). Cohorts consisted of approximately 100 individuals of each stage in each plot. The location of individuals on leaves was marked with a non-toxic felt-tip pen. The fate of each individual was then tracked by visual observation every 3-4 days. We attempted to estimate mortality due to insecticides, predators, parasitoids, and weather.

During both observational periods populations of *Bemisia* were relatively low. During the first period (19 July - 1 August) adults averaged 2.8/leaf, and eggs and nymphs averaged 3.6/cm^2 and 0.9/cm^2, respectively in our 3 study plots. Populations were even lower during the second period (8-23 August) with adults averaging 0.6/leaf, and eggs and nymphs averaging 0.4/cm^2 and 0.2/cm^2, respectively. In general, natural enemies appeared to be a greater source of mortality in fields treated with IGRs, however, life table studies were not conducted in replicated plots and robust statistical inferences cannot be made presently with our limited data set. In the first trial 38% of nymphs and 20% of eggs were killed by predators in a plot that had received three applications of conventional insecticides. In comparison, predator-induced mortality of nymphs and eggs ranged from 41-48% and 20-32%, respectively, in plots receiving 1-2 applications of bufrofezin and/or pyriproxyfen. Severe wind and rain during the first trial was also a major source of mortality for nymphs (23-41%); however, it was unclear whether some of these nymphs may have been killed by insecticides or other causes prior to dislodgment from the leaf. Insecticides killed 9-13% of nymphs in IGR plots and about 25% of nymphs in the conventional plot. Parasitism accounted for less than 2% of nymphal mortality in all plots. In the second trial weather was less of a factor. Predation of nymphs and eggs ranged from 21-35% and 11-25%, respectively, and there was no clear pattern in relation to insecticide regime. However, the conventional plot had not received an application for over 3 weeks prior to the initiation of this second trial. Parasitism of nymphs increased slightly (5%). Insecticides were a major source of nymphal mortality in fields treated with IGRs (30-52%), but had less of an impact (11%) in the conventional plot.

Based on this limited data set it is not possible to generalize about the impact of various mortality factors on the population dynamics of *Bemisia*. Additional observations will be needed, particularly in fields supporting higher population densities of the pest. We plan to continue these studies in 1997 in large replicated plots.

Investigator's Name(s): Steven E. Naranjo, T. J. Henneberry, and C. C. Chu.

Affiliation & Location: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: April 1995 - October 1996.

Progress in Development of Field Sampling Methods for Estimating Cotton Lint Stickiness

Cotton stickiness, due primarily to *Bemisia,* has become a limiting factor in cotton production in many countries, and, at present, may be considered by the cotton industry as the most serious factor affecting cotton quality. Enzyme-based technologies for ameliorating lint stickiness, either in the field or during harvest, are being developed. To most efficiently deploy these systems it will be necessary to determine whether a field is in need of remedial treatment for stickiness. Fairly standardized laboratory techniques (e.g. thermodetector) are available for indexing the stickiness of lint, but there is no standard methodology for collecting samples from the fields. Research was conducted in 1995 and 1996 in Maricopa, AZ and Brawley, CA to examine the distribution of sticky cotton lint, optimize the sample unit size, and determine the number of samples needed for the precise estimation of lint stickiness.

1995: Samples were collected on 1-4 dates at each of 5 field sites in Maricopa and Phoenix, AZ beginning about 2 weeks after the first appearance of open bolls. The frequency of chemical insecticide application was varied between sites in order to manipulate whitefly population densities and subsequent deposition of honeydew. Experimental sample units consisted of all open bolls on 1, 2, 5, 10, 20 or 30 consecutive plants. On a given sample date all six sample units were collected at each of five locations within each field along a diagonal transect. The time necessary to collect each sample was also recorded. Each lint sample was mixed, weighed and ginned. An aliquot from this mixed sample was then assayed for stickiness using the thermodetector method. This method provides a quantitative index of stickiness.

In general, analyses of the sampling distribution suggest that lint stickiness is uniformly to randomly distributed within cottonfields (SD/mean < 1). This pattern differs markedly from the highly clumped sampling distribution of *Bemisia.* The reason for this pattern is unclear, but may be related to the cumulative deposition of honeydew on lint over an extended portion of the season. Partitioning of variance components indicated that most of the variability is associated with differences between sample-unit in the field with very little variation between multiple thermodetector assays of the same sample-unit. Thus, it would be more efficient to allocate resources to collect more individual sample-units from the field rather than replicate thermodetector assays in the laboratory. There was generally no difference in mean stickiness readings between the 6 sample units examined. More importantly, there was little difference in the variability of stickiness readings among the 6 sample units. Relative net precision (a measure of the balance between precision and cost) declined dramatically with increasing size of the sample unit from 1 to 30 plants indicating that the small reduction in variation with larger sample units was not offset by the much greater cost (time) of collecting a larger sample unit. The 1-plant sample unit would probably be most cost efficient, but the 2-plant sample unit was most highly correlated with stickiness readings from bulk harvest samples. Further analyses of the 2-plant sample unit suggest that a precision (SE/mean) of 0.10 or 0.25 could be achieved by collecting about 24 or 4 sample units per field. Field collection time would range from 5-30 minutes depending on the desired precision.

1996: Results from 1995 indicated that smaller sample units were much more efficient for determination of lint stickiness. Thus, in 1996 we compared five smaller sample units at fields in Maricopa, AZ and Brawley, CA. As before a range of pest densities were established by differing frequencies of insecticide applications in 6 field sites at each location. Sample units consisted of all open bolls on 1 or 2 consecutive plants, or 5, 10 or 20 open bolls collected along an individual row. These three latter sample units consisted of bolls collected from all vertical strata on the plant. On two sample dates in Maricopa and one date in Brawley all five sample units were collected at each of ten locations within each field along a diagonal transect. The time necessary to collect each sample was also recorded. These samples are currently being processed.

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1992 - 1996.

Exponential Growth Phases of Silverleaf Whitefly in the Yaqui Valley, Mexico

The exponential growth phase (egp) of SLWF has been documented throughout the world. Different reports have indicated that a new egp has occurred two months earlier than the first egp; however, generally this information just registered the highest peak growth. This work includes the characteristics of the egp of SLWF in the Yaqui, Valley.

Since 1992, SLWF adults have been monitored weekly by yellow sticky tramps by 24 hours of catches. Degree days (from January 1, at 10-32.2°C) and adults catches were accumulated in order to calculated the regression equations of the egp by the best correlation coefficient.

Data show that the egp occurred by first time in this region in 1993. In this year, the egp was present from 2162 to 2499 accumulated degree days (add), in this year this period was ubicated from July 27 to August 17. The regression equation had a slope of 0.089 (r^2=0.95), with an highest peak of 14 adults/10 cm^2/24 hours. In 1994, the egp was present from 1692 to 2142 add (from July 5 to August 2). The regression equation had a slope of 1.28 (r^2=0.74), with an highest peak of 441 adults/10 cm^2/24 hours. In 1995, the egp was present from 1505 to 2033 add (from June 27 to August 1). The regression equation had a slope of 1.00 (r^2=0.92), with an highest peak of 212 adults/10 cm^2/24 hours. Finally, in 1996, the egp was present from 1540 to 2606 add (from May 21 to July 16). The regression equation had a slope of 0.14 (r^2=0.98), with an highest peak of 29 adults/10 cm^2/24 hours.

The differences of the characteristics of egp may be due to the presence of *Bemisia tabaci* in 1993 (32% of the *Bemisia* complex). Since 1994, SLWF is the dominant species. Apparently, the start of the egp has occurred earlier through time (1993, July 27; 1994, July 5; 1995, June 27; 1996, May 21), as well as its peak growth (1993, August 17; 1994, August 2, 1995, August 1; 1996, July 16), however, this is not true, if we take into consideration degree days, since in 1996 the egp has not show the same trend.

Among the characteristics of the egp studied, the slope could have been modified by the impact of the different actions of the IMP that have taken place in the region.

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Velvetleaf: A Possible Candidate for Enemy Free Space in Desert Agricultural Systems

Studies showed that *Eretmocerus* sp. nr. *californicus* is almost completely unsuccessful in parasitizing whiteflies on velvetleaf under greenhouse conditions. In the field, *Eretmocerus* might be entrapped, as are other parasitoids, although host whitefly density might influence this by altering the leaf on which hosts are found. Our studies of parasitoid behavior showed that reduced parasitism on velvetleaf is likely due to allocation of less time to searching velvetleaf and lower success at finding hosts. The rate of parasitism on the melons was approximately 40-80%, indicating that parasitoids reduce fitness of the whiteflies on melons. Parasitization recorded on velvetleaf was less than 1.0 %; indicating that whitefly fitness is likely higher on velvetleaf than on melons in the presence of parasites. These results support the case for enemy free space (EFS).

The final aspect needed to prove that velvetleaf provides enemy free space was the impact it has on the SLWF compared to melons. In our greenhouse study, while whiteflies would lay eggs on velvetleaf, the overall oviposition was lower on velvetleaf than on melons. This was due to the fact that whitefly adults sometimes became stuck in the resins of the velvetleaf hairs. Of the eggs that were laid on velvetleaf, a similar proportion emerged as adults as those laid on melons. This suggested that all plant hosts provided an equally suitable substrate for development. This supports the final hypothesis for EFS. Considering all of the data collected in these experiments, the presence of velvetleaf in the Imperial Valley provides an environment which is detrimental to natural control. The selective removal of this weed in the agricultural plant community may be a viable strategy to use in a regional IPM program.

Investigator's Name(s): D. J. Schuster.

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1995 - 1996.

Distribution of Immature Lifestages of the Silverleaf Whitefly on Tomato Plants

The intraplant distributions of eggs, sessile nymphs and pupae (red-eye nymphs) of the silverleaf whitefly were studied on tomato in the field. Five tomato plants were sampled weekly in a fall planting beginning three weeks after transplanting until fruit maturity. The numbers of eggs, sessile nymphs and pupae (red eye nymphs) were counted with a dissecting stereomicroscope on the lower surfaces of the terminal three leaflets of each leaf of the main stem and each leaf of one lateral branch. Leaves were numbered from the youngest to the oldest (i.e., from the terminal downward) beginning with the first leaf with the terminal leaflet fully formed, but not fully expanded. When stems bifurcated, the side branch was ignored in counting down the stem. Similarly, lateral branches and fruiting structures with accompanying leaves that arose from lateral or main branches were ignored.

The distributions of specific lifestages depended upon the age of leaves. Eggs were most abundant and variation generally low or lowest on leaflets at nodes 4-6, nymphs at nodes 6-8 and pupae at nodes 8-10. The nodal position of the most infested leaf tended to increase within the above ranges as the season progressed. The distribution of immature lifestages on leaflets at different nodes was independent of stem origination as long as the number of nodes present were similar on main and lateral stems. The *b* dispersion index from Taylor's Power Law for each lifestage did not vary significantly over nodes and over main and lateral stems within the above ranges of nodes for each lifestage. Single ln*a* and *b* values were calculated for each lifestage and were used to estimate minimum sample sizes (a sample unit consisted of the terminal three leaflets from the above respective nodes for each lifestage on either a main or lateral stem of one plant). Estimated minimum sample sizes at a precision of 0.25 (SE/mean) increased with increasing density of eggs but decreased with increasing density of nymphs and pupae. The minimum sample size did not exceed 23 and 28 for nymphs and pupae, respectively, at a density as low as one immature per sample.

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: 1995 - 1996.

Relationship Between the Density of the Silverleaf Whitefly and Symptoms of Irregular Ripening on Tomato

Experiments were conducted in the spring and fall of 1995 and spring of 1996 to study the relationship between the density of the silverleaf whitefly (SLWF) and symptoms of irregular ripening (IRR) on tomato in the field. Plots consisted of three 30 ft rows with 20 plants per row and were replicated four times in randomized complete blocks designs. The numbers of sessile nymphs and pupae of the SLWF were counted weekly on the terminal leaflet of the 7-8th leaf from the tops of 10 plants from the middle of each plot. Weekly counts of SLWF adults were made on the terminal three leaflets of the third leaf of 20 terminals of 10 plants from the middle of each plot. When predetermined densities of SLWF nymphs or pupae were reached, insecticide or insecticide combinations were applied. Check plots with no insecticide applications were included in the spring of 1995 and check plots treated with imidacloprid (Admire™) at transplanting followed by weekly applications of insecticides were included in all experiments. Red ripe fruit were harvested weekly and rated 1-4 for external symptoms of IRR and 1-5 for internal symptoms.

The relationship between the number of sessile nymphs/pupae and the external IRR rating for the two spring seasons was best, as indicated by highest r^2 values, when fruit ratings were compared to whitefly counts taken one week previously. In the fall, the best relationship was observed when fruit ratings were compared to whitefly counts taken two to three weeks previously. Thus, the impact of whitefly feeding was less in the fall than in the spring and the relationships between immature numbers and external IRR in the two spring seasons were very similar.

Similar relationships were observed with internal IRR ratings except that, when considering both spring seasons, the highest r^2 values were observed when IRR ratings were taken two weeks after nymphal and pupal counts were taken. Again, the impact of whitefly feeding was less in the fall than in the spring although the two spring seasons were less similar. In the fall, there was a poorer relationship between immature counts and internal IRR than between counts and the external IRR ratings.

The relationship between the number of SLWF adults and the number of nymphal and pupal SLWF subsequently observed was best when immature counts were taken two weeks after adult counts in the spring seasons and when immature counts were taken three weeks after adult counts in the fall. The relationships in the spring seasons were very similar and indicated that a greater number of nymphs and pupae would result in the spring relative to the fall for any given number of adults observed.

Investigator's Name(s): Wee L. Yee[1], Nick C. Toscano[1], D. L. Hendrix[2], and T. J. Henneberry[2].

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Research & Implementation Area: Section A: Ecology, Population Dynamics, and Dispersal.

Dates Covered by the Report: May - September 1996.

Effects of Insecticide Applications on *Bemisia argentifolii* (Homoptera: Aleyrodidae) Densities, Honeydew Production, and Cotton Yields

Honeydew contamination of cotton, *Gossypium hirsutum* L., lint by whiteflies, *Bemisia argentifolii* Bellows & Perring, is a major concern at textile mills and is well documented. Results of studies designed to determine adult whitefly densities at which cotton should be treated to reduce honeydew contamination have been variable. In this study, we determined the relationship between frequency of insecticide applications triggered by thresholds of 5, 10, 15, and 25 adult whiteflies per leaf and honeydew production on cotton. Honeydew production was monitored on 15 dates from 21 May to 27 August 1996 in Brawley, CA, using water-sensitive papers placed on upper and lower leaves and bolls. On 4 dates lint was collected and analyzed for sugars using high performance liquid chromatography (HPLC). Whitefly densities and honeydew production were both affected by frequency of insecticide applications. Densities of adults per 5th mainstem leaf, adults per 10-s vacuum sample, 1st and 2nd instars, and 3rd and 4th instars per square centimeter of leaf were generally higher in control plots (1 insecticide application), plots treated at 25 adults (4 applications), and untreated plots than in plots treated at 5, 10, and 15 adults (11, 6, and 5 applications, respectively). In general, numbers of honeydew drops per square centimeter were higher in control, 25 adult, and untreated plots than in 5, 10, and 15 adult plots. Papers placed on uppermost bolls received more drops later in the season than did papers placed on the lowest bolls. Honeydew production was low throughout the season when spraying was initiated at 5 adults per leaf, but was not significantly different than when spraying occurred at 10 or 15 adults later in the season. There was no difference in honeydew drop diameters among treatments. Trehalulose was more abundant on lint collected from control, 25 adult, and untreated plots than in 5, 10, and 15 adult plots. Honeydew drop densities were unexpectedly low in control and untreated plots on some later dates, especially on papers on bottom bolls. Coincidentally, control and untreated plants had fewer leaves than other plant during these times, suggesting leaf loss and plant level may account for some variability in honeydew production during late season. Seedcotton yields differed only between 10 and 25 adult plots. At Brawley, CA, insecticide treatments at 10 adults per leaf seemed sufficient for reducing whitefly honeydew production as much as the lowest threshold. Relatively few applications were needed to maintain the 10 threshold, which reduces immediate costs to growers and also reduces longer term problems associated with insecticide resistance.

TABLE A. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section A: Ecology, Population Dynamics, and Dispersal

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
A.1 Define biology, phenology, and demography of SLWF on greenhouse, field crop and wild host plants.	Year 5: Describe role of cultivated and wild host plants on the population dynamics of SLWF, identify weak links in seasonal biology.	X		Studies were conducted in cotton field to determine the influence of bloom removal, irrigation deficit, and insect growth regulator application on SLWF population dynamics. Bloom removal and moisture deficit conditions reduced SLWF densities. Predators and severe wind/rain were important sources of mortality in a partial life table study. The exponential growth phase of SLWF was documented in a study in the Yaqui Valley, Mexico. In a laboratory study on cantaloupe, SLWF progeny sex ratios were studied.
A.2 Develop efficient SLWF sampling plans for research and decision making purposes.	Year 5: Finalize sampling protocols.	X		Sampling plans for SLWF are in place for cantaloupe and cotton. The intraplant distribution of SLWF eggs, nymphs, and pupae were studied on tomato. Field sampling methods for SLWF honeydew and cotton stickiness were investigated in 1996. Lint stickiness was uniformly to randomly distributed within cotton fields compared with the highly clumped distribution of SLWF nymphs.
A.3 Develop economic thresholds for SLWF in relation to feeding damage, honeydew production and virus transmission.	Year 5: Continue economic analyses.	X		Economic thresholds for cotton were refined in 1996. The threshold for minimizing honeydew deposition was found to be between 5 and 10 SLWF adults per leaf. Studies were continued to quantify the relationship between SLWF density and tomato irregular ripening.
A.4 Develop and test population models to describe and predict SLWF dynamics.	Year 5: Identify existing information gaps in insect and plant interactions.	X		LandSat data were obtained and areawide models were developed and tested for the Imperial Valley. SLWF population data for various crops were linked to the cropping data and the effects of various cultural control strategies evaluated through this computer model.
A.5 Determine factors influencing SLWF dispersal and impact of dispersal on population dynamics in greenhouse, field crop, and weed host systems. (Combined with A.6 based on Year 1 recommendations)	Year 5: Summarize information on research progress on SLWF dispersal and propose needed research.	X		SLWF dispersal was studied in field and flight chamber/laboratory studies. Adult dispersal, and the influence of wind, was quantified from a cantaloupe field. Additional detailed studies on the effect of wind were conducted in the flight chamber. Knowledge of SLWF dispersal characteristics will be critical for designing efficient management strategies.

Reports of Research Progress
Section B. Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions
Co-Chairs: Jeff Shapiro and Judith K. Brown

Investigator's Name(s): J. K. Brown.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

A DNA Sequence Database for Subgroup III Geminiviruses

A database has been established in the Arizona laboratory that contains DNA sequences obtained from the middle 'core' region (550bp) of the coat protein gene. Sequences are obtained by PCR amplification of this gene region using universal PCR primers (Wyatt and Brown, 1996) that detect all whitefly-transmitted (WFT) (subgroup III) geminiviruses evaluated to date. PCR fragments are cloned into a suitable cloning vector, viral core sequences are obtained by automated sequencing of clones bi-directionally, and a consensus sequence is derived. Initial efforts have focused on archiving sequences for well-characterized geminiviruses, followed by addition of partially characterized isolates.

The CP gene is being evaluated as a useful molecular marker for geminiviruses for several reasons. The CP is the most highly conserved gene among the Geminiviridae. This can be seen by alignment of CP gene sequences of geminiviruses characterized to date, and functional evidence surrounding the role of the CP corroborates the observed sequence conservation. Constraints imposed on the coat gene are thought to include requirements for: strict virion capsid morphology, specific interactions between the capsid protein and the host plant, and capsid-vector specificity requirements with their insect vectors to achieve transmission. Our hypothesis is that these characteristics, collectively, make the gene particularly interesting and useful for making predictions about evolutionary relationships between geminiviruses. Alignment of coat gene sequences of the Geminiviridae resolves three major clusters of viruses corroborated by the current taxonomic scheme that considers three subtaxa within the family based on whitefly or leafhopper/membracid insect vectors and on a monocot or dicot host specialization WFT geminiviruses further resolve into two subclusters that correspond to either an Eastern or Western Hemisphere of origin. By this analysis the CP gene is informative about virus vector, host, and recent geographic origin.

Comparison of predicted CP sequences for the subgroup III Geminiviridae indicates a highly variable N-terminus, a nearly identical carboxy terminus, and a core containing identical regions interspersed with variable regions. Alignment of the 'core' or middle two-thirds of the CP gene resolves the same clusters as does alignment of complete coat gene sequence (Brown and Wyatt, 1996), and further resolves many subgroup III isolates into groupings based upon the original natural host of the isolate (Brown and Wyatt, 1996). This discovery suggested that predictions about vector and geography can be made from sequences within the core region alone, ultimately reducing resources required to archive the overwhelming abundance of new and emerging WFT geminiviruses, worldwide. Universal PCR primers have been designed to target this core CP region (Wyatt and Brown, 1996), permitting rapid detection, cloning, and sequencing of this marker, and detailed molecular comparisons between a plethora of uncharacterized geminivirus isolates.

The core CP database has application to virus identification, molecular epidemiology, and to an assessment of variability between isolates having similar core sequences. It is envisioned that the database will be used by international scientists for comparisons of core sequences from locally relevant viruses, and that users will provide additional sequences for newly described geminiviruses that have been sufficiently characterized. The database is also projected to include relevant biological data and key references to facilitate virus identification and ultimately, rational management of emerging geminiviruses, worldwide.

Investigator's Name(s): James Buckner[1], Dennis Nelson[1], Allen Cohen[2], Thomas Freeman[3], and Rita Ruud[1].

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: 1996.

Whiteflies on an Artificial Membrane and their Interactions with Predators

We have developed an effective apparatus for attracting adult whiteflies to the surface of an artificial membrane for feeding on a liquid media and to have female adults oviposit eggs by pushing the egg pedicel through the feeding membrane. Adult whiteflies fed and oviposited eggs on membrane assemblies containing water, but adult feeding activities and the production of stylet sheaths were improved by the addition of sucrose (7.5-30%) to the media. The eggs maintained on membranes with water or sucrose solutions developed normally and showed a high degree of hatch into crawling nymphs. To demonstrate the rate of water uptake by eggs on a membrane, a radiolabeled polysaccharide (inulin) was added to the media.

The feeding membrane was conducive for emerged nymphs to commence feeding and the wandering behavior of crawling nymphs was minimal. The ability of first instar nymphs to feed, attach and develop on membranes was dependent on the nature of the media. On a media of water, first instar nymphs commenced feeding but they survived only for a few days. On a media containing sucrose, feeding nymphs lived for several weeks, grew in size, showed development of dorsal wax projections, but the molting process to the second instar rarely occurred. We have observed molting from the first to the second instar for crawlers that were transferred from plant leaves to artificial membrane assemblies containing sucrose and a mixture of vitamins.

Light and scanning electron microscopy techniques were developed for observing the feeding structures on the media side of the feeding membrane (stylet sheaths, pedicels, etc.) that normally exist only within the leaf structure of whiteflies feeding on the underside of plant leaves. The coccinellid beetle, *Serangium parcesetosum*, has been identified as a promising predator of *B. argentifolii* that is amenable to artificial production. The feeding apparatus was used to study the interaction of *S. parcesetosum* larval predators with membrane-attached whitefly eggs and nymphs. The membrane surface with attached eggs and/or nymphs has served as suitable 'arena' for observing the feeding behavior of *S. parcesetosum* larvae that feed on only stationary prey. Since the stretched membrane and first instar nymphs are relatively transparent, the back lighting feature of the photomicroscope can be used to observe in detail the process of extraoral digestion by *S. parcesetosum* larvae. The system also has potential for 'dosing' whitefly nymphs (prey) with labeled compounds for the purpose of studying metabolism and nutritional requirements of whitefly predators.

Investigator's Name(s): R. Caballero[1], N. M. Anthony[2], R. ffrench-Constant[2], and J. K. Brown[1].

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: Jan. 1, 1996 - Dec. 31, 1996.

Monitoring Endosulfan Resistance and Frequency of Geminivirus DNA in Individual Whiteflies by Polymerase Chain Reaction (PCR)

The objective of this study is to develop PCR based methods for monitoring of insecticide resistance levels in the whitefly pest and vector, *Bemisia tabaci* (Genn.) and to determine the relative frequencies of potentially viruliferous whiteflies in agroecosystems in the southwestern U.S. Insecticide resistance is focused on monitoring frequencies of cyclodiene resistance imparted by a single amino acid replacement in the whitefly Rdl GABA gated chloride ion channel, and the frequencies of cotton leaf crumple geminivirus (Brown and Nelson, 1986) in whitefly populations in cotton. To accomplish this, two PCR based assays were developed in our laboratories and applied to evaluate the utility of the methods to predict: (1) the frequencies of whiteflies harboring genes for endosulfan resistance (Anthony *et al.* 1995, Anthony *et al.* submitted), and (2) relative frequency of whiteflies that have ingested cotton leaf crumple geminivirus DNA and are potential vectors of geminiviruses (Wyatt and Brown 1996).

Populations of *Bemisia tabaci* (Genn.) B biotype, were collected from field cotton in Safford and Yuma, Arizona, in August-September, during 1994, 95, and 96 and assayed for insecticide resistance using a discriminating dose bioassay. (Whiteflies were kindly provided by T. Dennehy, University of Arizona, Tucson, AZ.) Adult whiteflies were stored at -20 C until analysis was conducted. Preliminary results from analysis of 25 whiteflies per collection for endosulfan resistance indicated that Safford, AZ populations exhibited a very low frequency of resistance to endosulfan (less than 15%). In contrast, Yuma, AZ whitefly populations contained a higher frequency of individuals carrying the resistance allele (30-65%). Analysis of the same whiteflies for presence of ingested geminivirus indicated no virus in Safford populations, whereas, the Yuma population contained a moderate number of individuals that had ingested virus, ranging from 25-45% in the three years tested. These results have been corroborated by independent insecticide resistance bioassay data (Dennehy *et al.* 1995, 1996) and are consistent with respect to the histories of geminivirus disease incidence of the regions under study. For example, compared to Yuma, Safford is higher in elevation, has a cooler climate, is less diversified with respect to crops, has a history of absence of cotton leaf crumple geminivirus diseases in cotton problems, and fewer insecticide applications. In contrast, Yuma agroecosystems are at lower elevations, experience high temperatures, are highly diversified in crops that are hosts of geminiviruses, and typically require high insecticide inputs.

The application of PCR-based detection methods to analyze the same individual whitefly for endosulfan resistance and for the presence of ingested virus is unique among available assays to date. This approach has potential to permit predictions about the frequency of endosulfan resistance and about potential virus-vector capabilities in a population over time. One advantage of this approach, compared to bioassays typically used to determine frequencies of resistance or vector capacities is that whiteflies do not need to be alive, thereby enabling populations from different years and regions to be studied for comparison.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: 1995 - 1996.

CC Whitefly Adult Trap Improvements

In 1995, we developed a whitefly adult trap (CC trap). The trap can be used for monitoring migratory adult populations and seasonal fluctuations. However, fewer adults were caught compared to a commercial Dome traps (Trappit™, AgriSense, Palo Alto, CA) and yellow sticky card traps. We modified the CC trap design to retain more of the adults attracted to and entering the traps. Results showed that the modified CC trap caught more adults than Dome trap. On some occasions, the modified CC trap also caught more adults than the 3 x 5 inch yellow sticky card traps.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: March 1996 through December 1996.

In Situ Studies of Whitefly Feeding Biology

Electron microscopy studies of fractured leaves show that the feeding history is revealed in the patterns and structures of salivary sheaths produced by *Bemisia argentifolii* Bellows and Perring. Feeding structures within the leaves were of two kinds: salivary sheaths or actual stylets found in only a few of the many sheaths that were examined. In hundreds of observations of sheath structures, we found that mesophyll cells (spongy parenchyma and palisade) were not penetrated by stylets. Instead, we found that sheaths followed contours of cells, sometimes anchoring to the mesophyll cells. The sheaths were often found to form multiple branches, each with a 1.5-2.0 micron diameter, as was the main trunk that gave rise to the branches. All termination sites of branched sheaths were found to be closed-off, except where actual stylets were found to be present. At least 90% of all in-plant sheath material was found to be in the air spaces that predominate the spongy parenchyma. The only sheath material found to be within the leaf's symplast was that which was found in the epidermal cells. We often found peculiar spheroid structures that seemed to be sheath material that was not properly formed into sheaths. The spheroid structures were most commonly found within the epidermal cells or immediately adjacent to them. These studies confirmed earlier studies with conventional light and confocal microscopy showing that *B. argentifolii* are not mesophyll feeders.

Investigator's Name(s): Heather S. Costa[1], Nick C. Toscano[1], Donald L. Hendrix[2], and Thomas J. Henneberry[2].

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: 1996.

Periodic Pattern of Honeydew Production by Immature *Bemisia argentifolii*

Whitefly honeydew droplets were collected on water sensitive paper strips. A plastic cylinder was glued to the face of an appliance timer that completed a full rotation every 24 hours. A water sensitive paper strip was attached around the perimeter of the cylinder and placed under feeding whiteflies such that the strip collected honeydew continuously over a 24 h period. Droplets appeared as a line of blue spots on the yellow paper.

A periodic pattern of honeydew production by nymphs was observed. The pattern consisted of periods of droplet production (ON) followed by shorter periods where no honeydew droplets were produced (OFF). The mean ON periods increased in length from 2nd instar (mean ± SEM, 49 ± 1 min.) through early 4th instar (162 ± 1 min.). In most cases, late 4th instar (red eye stage) produced honeydew continuously (i.e., no obvious OFF periods). The length of OFF periods decreased slightly from 2nd instar (36 ± 0.8) to early fourth instar (23 ± 0.7 min.).

Molts were indicated by an extended OFF period followed by a noticeable increase in droplet diameter. A significant positive relationship was found between nymphal body length and diameter of the droplet produced ($P < 0.001$, df = 1,52, $F = 915.6$) (DIAMETER = 0.226 LENGTH- 0.022, $R^2 = 0.95$). The frequency of droplet production during ON periods decreased from first instar (80 ± 4 drops per hr) to fourth instar (22 ± 1 drops per hr). The periodicity of 1st instar nymphs was more difficult to determine as few cycles per individual were measurable. There did appear to be a cyclic pattern of production, however the drops were much more scattered and inconsistently detected in 1st instars compared to later instars. In several cases the first instar did not produce detectable levels of honeydew. The physiological significance of the periodic pattern of honeydew production is unknown.

Investigator's Name(s): W. Craig[1], P. F. McGrath[1], and I. Torres-Jerez[1], S. D. Wyatt[2], and J. K. Brown[1].

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1, 1996- December 31, 1996.

SqLCV: Evaluation of Strains in Homologous and Heterologous Combinations

The whitefly-transmitted squash leaf curl geminivirus (SqLCV) is a major constraint on cucurbit production in the Southwestern USA, Mexico, and Central America. SqLCV is as bipartite geminivirus and several strains have been identified. At least two strains, SqLCV-E and SqLCV-R are distinguished by the DNA sequences of their genomic components (Lazarowitz, 1991). SqLCV-E has an experimental host range of bean, squash and tobacco, while SqLCV-R also infects tobacco, but replicates only at low levels (or is less virulent) in bean, and squash (Lazarowitz and Lazdins, 1991; Ingham and Lazarowitz, 1993).

Several additional isolates of SqLCV have been described for which biological characters have been studied in detail, some with molecular studies undertaken (Brown and Nelson, 1984; 1986; 1989; Brown et al., 1995; Cohen et al., 1983; Polston et al., 1989; Rosemeyer et al., 1986). From these studies it appears that field isolates vary in host range, and may contain components of one or more strains, or from 2 to 4 genomic components. The extent to which the combinations of genomic components are present and the relevance of such combinations to host range, effective vectoring capacities, and distribution of particular strains in the field is unknown. Preliminary studies have been carried out to assess the frequency of components in field samples (Brown et al., 1995; Polston et al., 1989; Wendt et al., 1994).

Full length infectious clones of the A and B genomes of E and R strains (kindly provided by S. Lazarowitz) were used to biolistically inoculate a range of potential hosts: zucchini squash, pumpkin, melon, bean, watermelon, and *Nicotiana benthamiana* and *N. tabacum* 'Samsun'. Inoculations were made using homologous and heterologous A and B genome combinations, and the ability to infect this experimental range of hosts and symptom phenotypes were documented. Total DNA extracts were obtained from inoculated plants and assayed for geminivirus presence by diagnostic PCR using degenerate PCR primers that amplify a diagnostic 550 bp fragment of the coat protein gene from subgroup III geminiviruses (Wyatt and Brown, 1996). PCR primers that distinguish between the different E and A strain components (Brown et al., 1995) were also used to assess the composition of components in infected plants. Whitefly (*Bemisia tabaci,* B-biotype) transmission from infected source plants to zucchini indicator plants was conducted and infected plants were assayed by diagnostic and component -specific PCR.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: March 1995 - July 1996.

Feeding Chamber and Diet for Culture of Nymphal Silverleaf Whitefly, *Bemisia argentifolii* (Homoptera: Aleyrodidae)

A feeding chamber and diet were developed for rearing *Bemisia argentifolii* (Bellows and Perring) from eggs to fourth instar under aseptic conditions. The feeding apparatus consisted of a plastic diet chamber covered with stretched Parafilm® which was held in place by another piece of plastic and binder clips. Surface-sterilized eggs were placed on the Parafilm, and the chamber was incubated in a Petri dish at 90-95% relative humidity, 25-27°C and a photoperiod of 16:8 (light:dark). The most successful diet consisted of 5% yeast extract in 30% sucrose. Developmental times of first, second and third instar nymphs were 4.6, 3.4 and 4.2 days, respectively, which is comparable to development times on plants. Although whitefly nymphs can be reared on this diet to fourth instar, complete development to the adult stage was not achieved. The utility of the feeding system was demonstrated in bioassay with Ivermectin.® The whitefly parasitoid, *Encarsia* sp., oviposited and developed to adults on *B. argentifolii* larvae reared on the artificial feeding chamber. We suggest that this chamber will be useful for the study of the physiology, parasitoids, feeding behavior, and development of this insect, as well as for bioassay of potential intoxicants.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: July 1995 - December 1996.

Use of Satellite DNA Sequences as Species-Specific Probes for *Eretmocerus* and *Encarsia* Parasitoids

Parasitic wasps of the genera *Eretmocerus* and *Encarsia* are being investigated for use as biocontrol agents for whiteflies. A problem with their use is the difficulty of quick, easy and precise identification of species. Identification requires microscopic analysis by trained individuals. With release of geographic stains collected from all over the world it is critical that investigators be able to easily identify not only species but physiologically identical sub-species and geographic stains as well. We are developing a series of DNA probes specific to individual species for such identification. We have prepared genomic libraries of *Eretmocerus mundus* and *Encarsia formosa* and screened them for highly abundant satellite DNA sequences. Two different sequences have been isolated from each species and characterized by southern blotting and DNA sequencing. Each probe was hybridized with blots on which individual parasitic wasps from lines originally collected in numerous places around the world had been collected. The *Eretmocerus* probes, which had been originally isolated from a Spanish line, hybridized with all old world strains but not with several North American species/strains. The *Encarsia* probes, isolated originally from an Egyptian stain, hybridized with the parent strain and with two lines from Greece but with no other *Encarsia* species/strains from other parts of the Mediterranean or the rest of the world. We are further analyzing these satellite sequences to develop species/strain specific probes for parasite identification.

Investigator's Name(s): D. L. Hendrix, Y.-A. Wei, and Terry Steele.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1996 - December 1996.

Oligosaccharides in *Bemisia* Honeydew

Several novel oligosaccharides have been discovered in honeydew secreted by *Bemisia argentifolii*. Approximately 200 kg of cotton fiber contaminated with honeydew was washed, 1 kg at a time, in hot deionized water. After removing the fiber by centrifugation, finely divided activated charcoal was stirred into the extracts to adsorb the sugars. Sugars were removed from the charcoal with 95% ethanol which was removed by rotary evaporation. The remaining water was then removed by lyophilization leaving 1.5 kg of a dark brown syrup. This was fractionated using a large (12 x 85 cm) charcoal column eluted with 40 L washes of increasing concentrations (0, 2, 4, 6%) of *iso*-propanol . The sugars eluted with 6% propanol were collected and further separated using a large (4.8 x 120 cm) heated (65˚C) BioGel P-2 column eluted with deionized water. Unknown tetra- and pentasaccharides from this column were further purified using either anion-exchange HPLC or HPLC employing an amine column. The identities of purified oligosaccharides were confirmed using MALDI-TOF, 2D NMR and GC/MS of their alditol acetates. Among the unusual sugars identified in this fashion were:

bemisiose [α-D-Glc (1→4) α-D-Glc (1↔1) α-D-Glc];
bemisiotetrose [α-D-Glc (1→4) α-D-Glc (1↔1) α-D-Glc (4←1) α-D-Glc];
bemisiopentose [α-D-Glc (1→4) α-D-Glc (1↔1) α-D-Glc (4←1) α-D-Glc (4←1) α-D-Glc];
maltosucrose [α-D-Glc (1→4) α-D-Glc (1→4) α-D-Glc (1↔2) ß-D-Fru]; and
diglucomelezitose [α-D-Glc (1→4) α-D-Glc (1↔2) ß-D-Fru (3←1) α-D-Glc (4←1) α-D-Glc].

Chromatographic analysis of sugars in the 6% propanol fraction on an amine column suggested that the largest sugars in *B. argentifolii* honeydew were hexasaccharides, unlike honeydew from *Myzus persicae* or *Aphis gossyppi* in which the largest sugars are much larger (approximately decasaccharides). From analysis of acid digestion products of the 6% propanol fractions of various honeydews by HPLC it was determined that over 90% of the monosaccharides which make up the largest sugars in both *A. gossyppi* and *B. argentifolii* honeydew are glucose, the remainder being fructose. Analysis of enzymic digestion fragments suggested that most of the glucose in these large sugars was in the α-D configuration. From the structural similarity of many of the sugars in this excretia, it is assumed that they are created by transglycosylation reactions which add sugars one at a time to existing sugars. Some of the sugars in this honeydew are created by adding glucose units to trehalose (*i.e.*, the bemisiose series), other sugars are created by adding glucose to sucrose (melezitose, maltosucrose, diglucomelezitose, etc.). The discovery of maltosucrose is unexpected since erlose [α-D-Glc (1→4) α-D-Glc (1↔2) ß-D-Fru], a maltosucrose precursor in scale insect honeydew, is not present in this excretia.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: Jan. 1, 1996 - Dec. 31, 1996.

Frequencies of Whitefly-Mediated Transmission and PCR Detection of Geminivirus DNA in Two Whitefly Biological Types

Adult female whiteflies from colonies of two biological types, Arizona A and B (also *B. argentifolii*) of the *Bemisia tabaci* species complex, were studied for their ability to transmit tomato yellow leaf curl geminivirus from Thailand (TYLCV-Th) and chino del tomate geminivirus (CdTV) from Mexico. Single whiteflies were given an acquisition access period (AAP) of 0.5, 1, 2, 24, 48, or 72 hr on TYLCV-Th or CdTV infected tomato plants, followed by a 72 hr inoculation access period (IAP) on tomato seedlings. Experiments were replicated three times with ten test plants for each AAP. Whiteflies were collected after each AAP/IAP experiment and assayed to determine the frequency of ingestion of geminivirus using polymerase chain reaction (PCR). Geminivirus DNA was detected in whiteflies using degenerate PCR primers that facilitate the amplification of the core region (550bp) of the coat protein (CP) gene (Wyatt and Brown, 1996). Frequencies of detectable geminivirus ingestion by whiteflies, following the different AAPs tested, were correlated with frequencies of transmission of CdTV and TYLCV-Th to tomato by single whiteflies of the two biological types.

In transmission experiments, A and B biotypes were capable of transmitting TYLCV-Th and CdTV to and from tomato. In all virus-vector combinations, single insect transmission frequencies increased with longer AAPs. In general, TYLCV-Th was transmitted at a higher frequency by both biotypes than was CdTV. However, the B biotype, indigenous to the Eastern Hemisphere, was more effective at transmitting the Old World TYLCV-Th (87%), than was the New World A biotype (63%). CdTV, a geminivirus indigenous to the Western Hemisphere, was transmitted more often by the A biotype (50%), also from the New World, as compared to the Old World B biotype vector with 27% transmission.

Results of PCR-based detection of CdTV and TYLCV-Th in these two whitefly vectors indicate virus ingestion can be shown in single whiteflies given an AAP as short as 0.5 hr. For all virus-vector combinations, the frequency of virus detection by PCR steadily increased with longer AAPs, and reached 100% with a 72 h AAP. In general, PCR assays permitted earlier detection of virus ingestion by both whitefly biotypes than did the bioassay method. Clearly, PCR results are informative only about ingestion and therefore, of relative transmission potential. In contrast, transmission bioassays are based upon detection of a successful transmission event and demonstrate ingestion as well as vectoring ability. One of our goals is to determine if relative vector capacities can be estimated by PCR to document virus ingestion and hence, the number of potential carriers, in lieu of the more time-consuming bioassay that documents frequencies of experimental transmission events. In this study, geminiviruses were consistently detected earlier and at higher frequencies in whiteflies by PCR than by transmission bioassay, irrespective of the virus or the vector biotype. Thus, PCR-based methods that detect virus ingestion, but err on the high side, relative to estimates obtained from transmission bioassays, may be more than adequate to provide an indication of the relative number of whiteflies that may harbor virus within a field population over time. Given its speed and accuracy, this approach has great predictive potential for estimating the relative risk of whitefly-mediated virus transmission, albeit, standardization will likely be needed for given virus-vector combinations.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1 - December 31, 1996.

Artificial Induction of Plant Defensive Mechanisms May Affect Whitefly Populations

BTH (Ciba-Geigy; CGA 245704; benzo(1,2,3) thiadiazole-7-carbothioic acid S-methyl ester) is a commercial product that triggers a systemic acquired response (SAR) in plants. The production of pathogenesis-related (PR) proteins in plants is often associated with the SAR. We have tested the effect of BTH on adult whitefly oviposition preference and larval survival on collards. Control and BTH-treated collard plants (15 each) were exposed to whiteflies from a greenhouse colony for 7 h. Based on the numbers of eggs oviposited, the results show that whitefly oviposition was not affected by BTH. Other experiments were conducted using clip cages; approximately 40 adult whiteflies were allowed to oviposit on leaf #3 (from the top) of control and BTH-treated plants. After 1.5 h, the adults were removed, the eggs were counted, and the plants were placed into cages. The caged plants were placed in an environmental chamber set at 28C, 70% RH and a 16:8 light/dark cycle. Three weeks later we counted the number of whiteflies that completed their development (counts based on the number of empty pupal cases). About 86% of the whiteflies developed into adults on control plants, while only 38% of the whiteflies on BTH-treated plants did so. Preliminary field tests corroborate the laboratory experiments. These results suggest that artificial induction of plant defensive mechanisms may affect whitefly populations and may be used in control strategies.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: July - October 1996.

Correlation of Intracellular Punctures Produced by Adult *Bemisia argentifolii* with an AC Electronic Feeding Monitor Waveform

Electronic monitoring is the only methodology available for studying the stylet penetration behavior of whiteflies, a behavior that takes place beneath the surface of the plant. The stylet pathway of adult whiteflies in route to the phloem is largely intercellular, but they do make sporadic intracellular punctures during penetration. The ability to detect these intracellular punctures is of vital importance for studying the mechanisms of virus transmission by whitefly vectors and for studying the cues used by a probing whitefly during host selection. Before initiation of this study, only DC electronic monitors were capable of detecting intracellular punctures by whiteflies; the intracellular punctures are detected on DC monitors as waveforms called "potential drops". Since the AC electronic feeding monitor is the most common type used in U.S. labs and because the AC electronic feeding monitor has its own advantages (i.e., it can detect partial stylet withdrawals that are not currently known from DC electronic feeding monitors), we initiated a study to determine which waveform was the AC equivalent of the DC potential drop, and thereby correlate an AC waveform with intracellular punctures by the stylets.

In order to determine which AC waveform correlates with intracellular punctures represented by the DC potential drop, a switch was placed in series within the feeding monitor system, between an AC and a DC monitor. Electronic recordings were made from adult female *Bemisia argentifolii* of various ages feeding on lima bean, broccoli and cotton, using either the AC or DC system. Recordings were made using one system (either AC or DC) until the desired waveform appeared, and then the insect and substrate were switched over to the alternate system in order to determine the correlating waveform on the alternate system. In all switches, the AC pseudotransition waveform was found to be equivalent to the DC potential drop. The AC pseudotransition waveform was found to consist of 3 phases; phase I is characterized by a flat voltage level interrupted by downward spikes, phase II consisted a steady low voltage level with little fluctuation and finally, phase III was characterized by a high voltage level with little fluctuation. The DC potential drop was found to correlate with phases II and III of the pseudotransition waveform. Thus, the stylet tips are located within the plant cell only during phases 2 and 3. The fact that phase I is always recorded before phases II and III, suggests that these intracellular punctures are made intentionally by the insect while feeding, and are not accidental insertions of the stylet tips into the plant cells. Intracellular punctures were produced commonly during stylet penetration on all three plant species.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: August 1996 - present.

Identification of the *Bemisia argentifolii* Feeding Behavior that Results in Inoculation of Lettuce Chlorosis Virus

The feeding behavior of newly eclosed, adult female *Bemisia argentifolii* previously exposed to the semipersistently transmitted Lettuce Chlorosis Virus (LCV) was examined with an AC electronic feeding monitor. *Nicotiana benthamiana* and *Malva parviflora* served as both source and test plants for this experiment. In preliminary experimentation, the whiteflies were allowed to probe in the test plant, and upon reaching the phloem (determined by the electronic feeding monitor), they were allowed a 60 second period of phloem contact, during which salivation and ingestion presumably occurred in a sieve element. After 60 seconds of phloem contact, the probe in the test plant was artificially terminated. Following this exposure to the test plant, the whitefly was then placed on a second (indicator) plant for 24 hours in order to determine if it was viruliferous. Both test and indicator plants were assessed for virus symptoms 3 to 4 weeks later. These preliminary experiments suggest that the inoculation of LCV does not take place before reaching the vascular tissue or at any time within the first 60 seconds of phloem ingestion, however, more replicates are needed to verify this conclusion. Additional experiments are currently being conducted to determine if longer periods of phloem ingestion are required for virus inoculation, and if natural termination of phloem ingestion is required for virus inoculation.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Differential Gene Expression: A Comparison of the Silverleaf Whitefly and Sweetpotato Whitefly Using Differential RNA Display

Over the past two years, significant time has been spent in developing silverleaf and sweetpotato whitefly colonies from single mating pairs of whiteflies. After establishment on bean, these colonies were divided and equal portions transferred to squash and tomato, where they have been maintained. Mature and developing insects have been harvested from each colony. Differential display analysis has been initiated with both silverleaf and sweetpotato whiteflies. Display patterns comparing silverleaf and sweetpotato whiteflies of all developmental stages, of both sexes of adults, and reared on all three host plants indicate that the two species are virtually identical. Therefore, gene transcript differences which have been observed are likely to be relevant and not due to gene drift. Thus far twenty three clones have been identified and isolated. Of these 5 are species-specific, 3 are species- and juvenile-specific, 6 are adult-specific and 4 are host plant-specific. We are in the process of screening these clones by DNA blot hybridization and RT-PCR. *In situ* hybridization will be used to determine their spatial expression in the insect. Currently, studies assessing the ability to induce squash leaf silvering of silverleaf whiteflies of different developmental stage are in progress.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1 - December 31, 1996.

Pathogenesis-Related Proteins in Tomato Plants as a Result of Silverleaf Whitefly Feeding

Bemisia argentifolii has been shown to induce a number of pathogenesis-related (PR) proteins in tomato plants as a result of feeding (Mayer et al. 1996). We have confirmed this effect in collard plants and suspect that this is a general effect of silverleaf whitefly feeding. Collards infested with whiteflies for two weeks had significantly elevated levels of chitinase (1.3 ± 0.2 vs. 0.8 ± 0.1 DA_{550}/min/mg protein in controls), b-1,3-glucanase (1.5 ± 0.2 vs. 0.8 ± 0.1 Glc/min/mg protein in controls), and peroxidase (5 ± 0.7 vs. 3.1 ± 0.4 DA_{510}/min/mg protein in controls). Foliar lysozyme levels appeared to be elevated (71.5 ± 26.9 vs. 49.1 ± 21.6 DA_{510}/min/mg protein in controls) and leaf protein content was essentially unchanged (0.5 ± 0 vs. 0.6 ± 0.1 mg protein/g tissue in controls). We performed similar experiments with cabbage loopers (*Trichoplusia ni*) to determine if the ability to induce multiple PR proteins by whiteflies was unique. Only chitinase was significantly induced by cabbage looper feeding (0.7 ± 0.4 vs. 0.2 ± 2 DA_{550}/min/mg protein in controls).

Because we have observed few insect herbivores occupying the same host plant with whiteflies, it may be that induction of PR proteins or other substances deter or affect herbivore competitors. Cabbage looper larvae (1^{st} instar) were fed leaves from collard plants previously infested by whiteflies for two weeks and the effects on development observed. Consumption rate (leaf weight; 3.4 ± 0.2 vs. 4.4 ± 1 g in controls) and approximate digestibility ((wt. of food ingested) - (wt. of feces/ wt. of food ingested); 0.5 ± 0 vs. 0.6 ± 0 in controls) were significantly reduced in the test group (fed whitefly infested leaves). The efficiencies of conversion of ingested food to body substances (larval wt. gained/wt. of food ingested; 0.3 ± 0.1 vs. 0.1 ± 0 in controls) and the efficiency of conversion of ingested food to body substance (larval wt. gained/wt. of food ingested; 0.09 ± 0 vs. 0.06 ± 0 in controls) were elevated indicating that although less food was consumed test larvae were more efficient in converting ingested food to body substance. Developmental time was also significantly affected; test larvae took 2.5 days longer to pupate than did control larvae. Collard plants (uninfested and previously infested to whiteflies) were transplanted into field plots in randomized fashion and 1^{st} instar cabbage loopers were placed on the plants (2 larvae/plant). There was a significant difference in the pupation rate; 18% of the larvae on the uninfested plants pupated whereas only 4% of those on infested plants did.

These experiments suggest that induction of multiple PR proteins resulting from feeding by silverleaf whiteflies may be unique. Also, induction of PR proteins and/or other substances in plants infested by silverleaf whiteflies may be a mechanism(s) by which competition from other herbivores is reduced.

Mayer, R. T., McCollum, T. G., McDonald, R. E., Polston, J. E., and Doostdar, H. *Bemisia* feeding induces pathogenesis-related proteins in tomato. In: *Bemisia* 1995: Taxonomy, biology, damage, control and management. (D. Gerling and R. T. Mayer, Eds.) Intercept Ltd., Andover, Hants, UK. pp.179-188. 1996.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Whitefly-Transmitted Geminivirus Diseases of Cotton: An International Problem

During the last decade, whitefly-transmitted (WFT) geminiviruses have emerged as important pathogens in subtropical and temperate agricultural systems, worldwide, with diseases resulting in dramatic yield reduction. Economic losses due to WFT geminiviruses now occur in cotton, as well as in bean, tomato, tobacco, pepper and cassava. Changes in agricultural practices, such as the increased use of irrigation and pesticides, together with increased international trade, and the dispersal of a 'new' biotype of the whitefly vector *Bemisia tabaci* (Genn.) have likely contributed to present-day problems.

WFT geminiviruses have a unique 'paired' or geminate virus particle composed of coat protein subunits encapsidating a single-stranded, circular DNA genomic component. Experimental host ranges and complete genomic DNA sequences have been determined for numerous WFT geminiviruses, and these biological and molecular data can be used to facilitate identification and tracking of distinct viruses and strains, thereof. Many WFT geminiviruses are known to infect more than one cultivated host species and numerous several weed species, confounding management aspects toward disease control. Effective approaches to disease control require correct identification of the WFT geminiviruses pathogens and a knowledge of which cultivated and/or weed species a particular geminivirus infects. Molecular information in conjunction with biological studies are needed to confirm virus identity and to track the distribution of geminiviruses across diverse geography's and in cultivated and weed hosts.

To date, the majority of geminiviruses infecting cotton are poorly studied. Our objective is to develop a geminivirus DNA sequence database that contains sequences of key regions of the virus genome that will facilitate identification of WFT geminiviruses, and mapping of their distribution, worldwide. To better understand the evolutionary history of cotton-infecting geminiviruses and interpret responses of viral genotypes to germplasm genotypes, a second objective is to determine degrees of sequence similarity and to ascertain the extent of variability between the most predominant cotton-infecting geminiviruses. This information must be coupled with that about experimental host ranges, and characterization of their relationships with geographically relevant biotypes of the vector whitefly. Geminivirus DNA sequence analysis is currently focused on a conserved region, or the core of the coat protein gene (Wyatt and Brown, 1996) which has been proposed to be a useful evolutionary indicator among WFT geminiviruses (Brown & Wyatt, 1996). The core region of the coat protein gene has been sequenced for numerous WFT geminivirus isolates, and over twenty sequences have been obtained for geminivirus isolates from cotton and related host species. Future work will focus on obtaining and investigating isolates from India, Pakistan, Australia and countries in Africa, and all of the Americas. In depth studies will be carried out on select cotton-infecting isolates, with the long-term goal being the production of transgenic cotton with resistance to the geminiviruses infecting cotton worldwide. Another long term goal is to place the geminivirus DNA sequence database on the Internet to make the information accessible for the worldwide community.

This research is funded in part by the Common Fund for Commodities-Cotton and by Cotton Incorporated.

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Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Why Polyphenism is Important in Polyphagous Whiteflies, Why Whiteflies are White, and the Relationship of these Behaviors by the Silverleaf and Greenhouse Whiteflies to Cultivar Selection in Plant Resistance

Of the approximately 1,200 described species of whitefly, some are monophagous but most are oligophagous. Very few, such as the sweetpotato/silverleaf (*Bemisia* complex), and greenhouse whitefly *Trialeurodes vaporariorum*, are polyphagous and known to develop on some two to three hundred plant species (note that Mound and Halsey 1978, recognize three polyphagous species, the third was *Aleyrodes proletella*). Thus, for the polyphagous species of whitefly, specific host plant would not appear to be a primary or critical need.

Variability of the morphological characters of the pupal exuviae of polyphagous whiteflies is also very different from the monophagous and oligophagous species. In both monophagous and oligophagous species, the number of dorsal setae and lateral secretions of wax filaments have their own recognizable character and are consistent regardless of host. Polyphagous species generally do not secrete long lateral wax filaments on the pupal exuviae, however the number of *dorsal* setae on *Bemisia* complex and *dorsal* wax extrusions on *Trialeurodes* sp. are variable. The variability in the way a pupa exuviae "shows itself" is well established. We reported in the previous conference (no. 4), that variability in the pupa of both species is an individually adaptive response dependent on the experience of the crawler to features on the host leaf surface prior to settling and is *independent of host trichomes*. High populations density or whitefly crowding on a smooth leaf surface results in pupal dorsal setae and wax extrusions. This finding has been supported in additional studies this past year.

The adults of all whitefly are white with very few exceptions. Whiteness is due to clusters of small lipid particles, secreted from paired ventral abdominal glands during the teneral period, being transferred by the hind legs and set loosely attached to hooks arranged in rows on each wing. Waxing occurs ***before*** any feeding. It is the consistency of "waxing" behavior that gives a uniform appearance to most whitefly species. Chemical composition analyses of the `wax' secretion from several whitefly species has been reported and showed there were differences in composition among species; however, despite the differences, *there is no difference in the physical property* of the waxes but the wax is critical.

We propose the following based on the observed variables of *apparently independent* behavior that occurs in polyphagous species that tend to over-colonize host plants and results in adult dispersal. (1) Polyphenism is critical to polyphagous species because the progeny of a pioneering female that emerged on a host with glabrous leaves, dispersed and oviposited on a host with hirsute leaves, could receive some `look-alike' form of protection from either predation or parasitism. It is the progeny of the pioneering female that require protection because they are developing in a niche different from the maternal. (2) The loosely attached wax particles protect new adults that emerge on a surface with sticky trichomes and glandular hairs. Wax also allows species to freely move about and exploit hirsute hosts with glandular trichomes that other insects must avoid. An example is the monophagous azalea whitefly that develops only on *R. mucronatum*, an azalea notorious for its dense glandular trichomes and sticky hairs. Finely, a perusal of the extant literature on available reports of host resistance studies of polyphagous whiteflies when the effect of leaf trichome density on preference is compared, consistently showed that whiteflies *in all cases demonstrate a strong preference for hirsute over a glabrous surface*. Thus, as a family, whiteflies are prepared to tread where most insects fear to go to escape the chase by *Encarsia* and generalist predators.

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Dates Covered by the Report: September 1, 1995 - August 31, 1996.

Fate of Squash Leaf Curl Virus in Squash

Immunogold silver staining-light microscopy (IGSS-LM). Thin sections (1-µm thick) of SLCV-infected, leaf-tissue specimens were individually mounted in droplets of water on glass slides coated with 0.01% poly-L-lysine, dried at 40°C, rinsed in 0.01 M Phosphate Buffered Saline (PBS), pH 7.4, and incubated with blocking buffer [5% normal goat serum (NGS) in PBS, pH 7.4, containing 0.1% Bovine Serum Albumine (BSA) for 30 min at RT]. After five rinses in PBS, tissue sections were incubated for 2 h at RT with anti-SLCV polyclonal immunoglobulin (IgG); serially diluted 1:100, 1:500 or 1:1000 in 0.01 M PBS containing 0.1% BSA, 1% NGS and 0.02% NaN_3 (PBS-BSA-NGS-NaN_3), pH 7.4; rinsed in PBS (6x5 min) and labeled with goat-anti-rabbit IgG:5nm-gold conjugate (Ted Pella Inc.) for 1 h. The gold conjugate was diluted 1:30, 1:50 or 1:100 (v/v) in PBS-BSA-NGS-NaN_3 and applied at a rate of 100 µl per section. Sections then were rinsed in PBS and distilled water, stained using a Silver Enhancer Kit (Anonymous, 1983), post-stained with methylene blue and basic fuchsin, and viewed and photographed under a Zeiss Standard 25 compound microscope.

Immunogold-transmission electron microscopy (IG-TEM). Ultrathin sections (70-nm thick) were collected on formvar-coated nickel grids and floated face down for 15 min on drops of 0.02 M glycine in TRIS-Buffered Saline (TBS:20 mM TRIS-HCl, pH 7.6, plus 225 mM NaCl) to inactivate residual aldehyde groups present after aldehyde fixation. The grids then were transferred for 20 min to blocking buffer (0.1% BSA, 0.05% Tween 20 and 0.02% NaN_3 in TBS, pH 7.6) containing 5% NGS to block the nonspecific antibody binding sites. Following incubation in anti-SLCV IgG diluted 1:100, 1:500, 1:1000 or 1:2000 in blocking buffer supplemented with 1% NGS, ON at 4°C, and rinsing in blocking buffer, the grids were transferred to goat-anti-rabbit-IgG:5nm-gold conjugate diluted to 1:50, 1:100 or 1:150 in blocking buffer for 1 h at RT, rinsed first in blocking buffer then in distilled water and stained with 4% aqueous uranyl acetate and Reynolds lead citrate. Sections were examined in a Zeiss 10C TEM at 60 V. Areas of specimen blocks for ultrathin sectioning were selected on the basis of light microscopic examination of thin sections labeled with gold and enhanced with silver.

Controls. For light and electron microscopy, sections of SLCV-infected leaf tissue were subjected to nonimmune rabbit serum or blocking buffer or antiserum to lettuce infectious yellows virus (LIYV) as the substitute for the primary antibody prior to immunogold labeling and silver enhancement. Additionally, SLCV-free leaf tissue was first exposed to anti-SLCV IgG, followed by immunogold labeling and silver enhancement. Thin sections were post-stained with methylene blue and basic fuchsin and ultrathin sections with uranyl acetate and lead citrate.

Squash leaf curl virus (SLCV) was localized by immuno-gold-silver staining light microscopy (IGSS-LM) in nuclei of phloem parenchyma cells and in sieve elements of zucchini squash, *Cucurbita pepo* L. Labeling was absent from cells of the abaxial and adaxial epidermis, palisade and mesophyll parenchyma cells and tracheary elements. SLCV was localized by immunogold transmission electron microscopy (IG-TEM) in nuclei of phloem and xylem parenchyma cells and immature, maturing and mature sieve elements. Virus-induced inclusion bodies and aggregates of virions were observed in nuclei of phloem parenchyma cells and immature sieve elements. The most prominent cytopathological changes associated with SLCV infection occurred in nuclei, nucleoli, chloroplasts and mitochondria of phloem parenchyma cells. Nuclear changes included lobing, hypertrophy, degeneration, depletion of chromatin and the appearance of fibrillar bodies characteristic of geminivirus infections. Breaks in the nuclear membrane and release of virions into the cytoplasm occurred in later stages of infection until the nuclei were no longer distinct entities and virions and virus aggregates filled the cell lumen. Mature sieve elements were enucleated and contained primarily strands of P-protein, and small aggregates of SLCV virions labeled with gold. Gold-labeled SLCV also was observed in the cell walls between sieve elements and phloem parenchyma cells, between sieve elements, and between phloem and xylem parenchyma cells. The size of SLCV particles *in situ* was 14-15 nm for monomers and 14x30 nm for dimers.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

The Tomato Defense Response to Silverleaf Whitefly Feeding

The silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, causes millions of dollars in damage to U.S. producers each year. In addition to direct feeding and virus vectoring, this insect causes unusual developmental disorders in a number of plants. One of these disorders is the irregular ripening of tomato fruit. These fruit cannot be marketed because only a portion of the fruit ripens and the other portion stays green. These irregularly ripened fruit are unresponsive to exogenous ethylene treatment. To date there are no published reports on how or why silverleaf whitefly feeding causes these effects in tomato. The purpose of this project is to assess the response of known defense-regulated genes in response to the phloem-feeding silverleaf whitefly. The two methods that have been implemented are Northern blot analysis and RNA differential display. Using cDNA probes to pathogenesis-related protein gene transcripts, we have demonstrated that PR mRNAs (e.g., PR1a...) accumulate in response to silverleaf whitefly-infested and greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood),-infested leaves of tomato plants. In addition, the PR transcripts are induced in apical non-infested leaves. Transcript levels for several wound-response genes (proteinase inhibitor I and II and leucine aminopeptidase and phenylalanine ammonium lyase) were monitored in infested and non-infested leaves. While all wound-response genes were induced by *Pseudomonas syringae* pv. *tomato* and mechanical wounding, only PAL was induced in response to whitefly feeding. RNA differential display has also been used to determine changes in tomato gene expression in response to silverleaf whitefly and greenhouse whitefly infestations. Several genes induced specifically by silverleaf and greenhouse whitefly feeding, and not when the tomato leaf is either wounded or infected with *Pseudomonas syringea* pv. *tomato* have been identified. Using the two complementary methods (Northern blot analysis and differential display) will not only lead to the characterization of known defense gene expression in tomato, but has lead to the cloning and characterization of novel defense-regulated genes from silverleaf whitefly-infested tomato leaves.

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Dates Covered by the Report: January, 1996-December, 1996.

Temporal Monitoring of Geminivirus in Whitefly Hemolymph Using Polymerase Chain Reaction (PCR)

Our long term goal is to elucidate the pathway of geminivirus particles through their whitefly vector, *Bemisia tabaci* (Genn.). In previous studies, we utilized feeding by whiteflies in a simulated transmission chamber and PCR to monitor squash leaf curl geminivirus (SqLCV) DNA in adult whitefly whole body extracts, in sucrose substrate into which whiteflies salivate during ingestion of food from the chamber, and in whitefly honeydew excreted in droplets that fall to the bottom of the chamber. In these studies, SqLCV DNA was readily detectable by PCR in saliva, honeydew, and in whole body extracts of *B. tabaci*, allowed to ingest virus from geminivirus-infected plants prior to placement in a chamber. A non-vector whitefly, *Trialeurodes vaporariorum* (West.)/the greenhouse (GH) whitefly, was also allowed to ingest SqLCV from infected plants before transfer to a feeding chamber. Viral DNA was detectable in honeydew and in whole body extracts, but not in the saliva/sucrose fraction of the non-vector. In light of the ability of the greenhouse whitefly to feed successfully in the phloem and ingest virus from infected plants, as does the whitefly vector (Polston et al, 1990, *Phytopathology* 80:850), acquisition and transmission of virions should, theoretically, also be possible. However, the GH whitefly appears to be unable, ultimately, to transmit geminiviruses. Whether specific barriers exist exclusively at salivary system/hemolymph interfaces, and/or at the gut/hemolymph interface as well, is not known. In pursuing the identity of specific sites of interaction between geminiviruses and their whitefly vector that may facilitate vector-specific transmission of subgroup III geminiviruses, the following objectives were pursued: 1) to devise a method of collecting and analyzing hemolymph from adult whiteflies for the presence of virus DNA; 2) to temporally monitor SqLCV DNA in the hemolymph of the whitefly vector, and 3) to determine if and when, SqLCV DNA is detectable in hemolymph of the non-vector whitefly.

Virus-free adult *B. tabaci* female whiteflies were given acquisition access periods (AAPs) of 0.5, 2, 4, 8, 12, 24, 48, 72 and 96 hours on healthy or SqLCV-infected pumpkin. Virus-free adult *T. vaporariorum* were allowed 2, 12, and 24 hr AAPs on healthy or SqLCV-infected pumpkin. Whiteflies were collected after each AAP and cooled to arrest movement. Whiteflies were attached to parafilm using a fast drying glue, covered with mineral oil, and hemolymph was collected from individuals. Removal of a hindwing caused the whitefly to "bleed" a drop of hemolymph which was collected by aspiration with a sterile glass 1-5 µl capillary pipette pulled to a fine point (~0.5 µm diameter). Samples were diluted into 50 µl Tris/EDTA buffer (pH 8.0) containing 0.01M phenylmethyl sulfonyl fluoride (PMSF). SqLCV DNA was monitored in hemolymph samples collected after each AAP using PCR to detect a diagnostic fragment (550bp) of the virus coat protein gene (Wyatt and Brown, 1996, *Phytopathology* 86: 1288). SqLCV was detected in individual *B. tabaci* given a 2h AAP on virus-infected plants, indicating that geminivirus is present in whitefly hemolymph shortly after feeding is initiated on virus-infected plants. Virus DNA was also detected in the hemolymph of vector whiteflies fed on infected pumpkin for all subsequent AAPs up to and including 96 hours. In contrast, SqLCV DNA was not detectable in the hemolymph of individual *T. vaporariorum* at any AAP tested. These results suggest that the digestive system epithelia of the non-vector whitefly serve as an effective barrier to prevent the passage of geminivirus into the hemolymph. In *B. tabaci*, however, the digestive system epithelia provide points of specificity, possibly receptors, that allow geminiviruses to traverse epithelial cells.

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Dates Covered by the Report: January, 1996-December, 1996.

Digestive Tract Size Exclusion in Nymphal and Adult Whiteflies

Bemisia tabaci (=B. argentifolii), is a major pest of cotton, melon, tomato and other crops in agroecosystems, worldwide, and is a vector of geminiviruses (Brown, 1994, *FAO Plant Prot. Bull.* 42:3). This whitefly has been reported to transmit the bacterium, *Agrobacterium tumifaciens* (Zeidan & Czosnek, 1994, *Molec. Plant-Microbe Inter.* 6:792) based on the production of tumors in inoculated plants. A number of bacteria, including *Bacillus* spp., *Staphylococcus* spp., *Pseudomonas* spp., and several unidentified bacteria have been isolated from surface sterilized larvae and adults using standard bacteriological media (Davidson et al, 1994, *J. Insect Physiol.* 40:1069) and co-culture with cultured mosquito cells (Davidson et al, unpublished). It is likely these latter bacteria were in the digestive tract or in orifices protected from contact with the sterilizing agents. The diameter of the food canal in adult *B. tabaci* is estimated to be 0.65 µm (Rosell et al, 1995, *Int. J. Insect Morphol. Embryol.* 42:297; Cohen, unpub), and thus, minimally wide enough for possible passage of bacteria ranging from 0.5- 1.0 µm in width (Holt et al, 1994, *Bergey's Manual of Determinative Bacteriology*). In contrast, geminiviruses are 20x30 nm in size, and should readily pass into the digestive tract.

The objectives of this study are: 1) to investigate the size exclusion limits of the mouthparts and digestive tract, seeking to clarify the maximum size of microorganisms which could reasonably pass into and through the whitefly digestive tract, and 2) to study the osmoregulatory function of the highly complex filter chamber, which reportedly separates nutrients in low concentration from large volumes of water and sugars, and differentiates chemical and osmotic composition of phloem fluids (Harris et al, 1996, in *Bemisia '95: Taxonomy, Biology, Damage, Control and Management*;. p. 289; Marshal & Cheung, 1974, *Tissue & Cell* 6:153).

Fluorescent-labeled materials spanning a range of sizes were fed to adult whiteflies using an artificial feeding chamber, or to larvae in a feeding system (Jancovich et al, 1996, *J. Econ. Entomol.* in press) in which materials were presented to feeding larvae in artificial diet. Small molecular weight probes of Lucifer yellow, 521 Da, completely filled adult and larval digestive tracts shortly after feeding was initiated. Fluorescence filled the entire midgut and hindgut, and fluorescent honeydew was produced. Larger molecular weight dextran probes of 4400 Da and 2 million Da also entered and filled the entire gut, including the midgut, within a few minutes after feeding was initiated. Both probes were evacuated after whiteflies were removed from fluorescent sources, resulting in production of brightly fluorescent honeydew. Fluorescent-labeled latex spheres were ingested more slowly than materials of smaller molecular weights. After one day of feeding on spheres of 0.1 or 0.2 µm, fluorescent beads were observed in the entire gut, including the midgut, and in the honeydew. Spheres lined the midgut, apparently adhering to the filter chamber and midgut apical surfaces. Spheres of 0.5 and 1.0 µm in size were never observed in the midgut or the honeydew, even after extended feeding times. From these studies, there is no evidence of selective or direct shunting of macromolecules ranging from 512 Da to 2 million Da in size, or for movement of molecules as large as 0.2 µm from the filter chamber into the hindgut. Based on the results of size exclusion limit studies, adult and larval digestive systems appear to be quite similar, and large diameter spheres are excluded from the digestive system, probably due to a size limitation of the stylet food canal.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: January - December, 1996.

Effect of Sucrose Concentration on Carbohydrate Metabolism in *Bemisia argentifolii*: Biochemical Mechanism and Physiological Role for Trehalulose Synthesis in the Silverleaf Whitefly

Uptake and metabolism of sucrose by adult silverleaf whiteflies (*Bemisia argentifolii*) were investigated on defined diets containing sucrose concentrations from 3 to 30% (w/v). At an optimal pH of 7, the volume of liquid ingested decreased with increasing dietary sucrose concentration, but the amount of sucrose ingested showed a net increase. Above a dietary sucrose concentration of about 10%, a greater amount of the ingested carbon was excreted by the whiteflies than was retained, and the proportion that was excreted increased progressively with increasing dietary sucrose concentration. Carbohydrate analysis showed that the composition of excreted honeydew changed from predominantly glucose and fructose at low dietary sucrose concentrations to predominantly trehalulose at high concentrations, with little change in the proportion of larger oligosaccharides. Measurements of whitefly trehalulose synthase and sucrase activities revealed that the enzymatic potential for metabolizing sucrose shifted from favoring sucrose hydrolysis at low sucrose concentrations to sucrose isomerization at high sucrose concentrations. Thus, the amount of trehalulose synthesized by the silverleaf whitefly was directly related to the properties of trehalulose synthase and sucrase and the concentration of sucrose in the diet. We propose that trehalulose is synthesized for excretion when the carbon input from sucrose is in excess of metabolic needs.

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Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Accumulation and Reduction of mRNA Transcripts in Squash Leaves Upon Which Silverleaf Whitefly Has Fed

Physiological leaf silvering has been know to occur in squash, *Cucurbita pepo*, for a number of years. Silvering begins parallel to the veins in the upper leaf surface and spreads until the entire surface is completely silvered. The lower leaf surface seems unchanged. Stems, petioles, flowers and fruits are affected. Only recently it was found that silverleaf whitefly (SLWF), *Bemisia argentifolii* Bellows and Perring induces silverleaf symptoms in squash. Other whitefly species such as the sweetpotato whitefly (SPWF) *Bemisia tabaci* (Gennadius) biotype A, or the greenhouse whitefly (GHWF); *Trialeurodes vaporariorum* (Westwood) do not cause squash silverleaf (SSL) symptoms. Our long term goal is to identify the mechanism that controls the squash silvering disorder. We hope to identify genes that are induced or suppressed by whitefly feeding or more specifically by SLWF feeding. This should allow us to determine if the responses to whiteflies are distinct or similar to the responses that are observed during pathogen invasion. Zucchini (cv. *chefini*) plants were either infested with SLWF or SPWF, or served as noninfested controls. The plants were monitored for 7 weeks for leaf silvering, leaf blade length and width, and petiole length. Leave blades were harvested directly into liquid N2 and stored at -80°C for RNA isolation and RNA differential display. Squash silverleaf symptoms were detected only in SLWF infested plants and not in SPWF infested or non-infested plants. No differences in leaf blade length, width or leaf blade expansion were detected between SLWF, SPWF and non-infested plants. However, the petioles from the SLWF infested plants were significantly smaller than those of the SPWF or non-infested plants. Specifically, the symptomatic leaves had shorter blanched petioles. RNA blots, containing RNA from 3 leaf-stages of all 3 treatments and from *Pseudomonas syringae* infected squash leaves, were cross hybridized with 3 wound response genes (ß 1-3 glucanase, class III chitinase and peroxidase). None of the genes were induced in the SLWF, SPWF or non-infested leaves, but were induced in *P. syringae* infected leaves.

In RNA differential display (DD) small amounts of total RNA were reverse transcribed (RT) using 1 out of 12 anchored primers (representing the total mRNA population) to synthesize cDNA. In a PCR reaction the same anchored primer together with a random primer in the presence of radioactive dATP was used to exponentially amplify cDNAs, which was visualized by denaturing polyacrylamide gel electrophoresis (PAGE) and exposure to X-ray film. Changes in gene expression were reflected by the presence or absence of cDNAs. Four classes of genes were identified using 7 primer pairs for RNA DD: 1) Constitutive expressed genes, 2) Developmentally regulated genes, 3) Whitefly defense response (WDR) genes. 4) SLWF response (SLW) genes. From these primer pairs, 11 differentially regulated genes were reamplified from the gel. Nine were WDR genes and two were SLW genes. WDR genes may be involved in the plant defense response to whitefly feeding, and can be either induced or suppressed. We found 3 WDR genes being suppressed and 6 induced in infested plants. Correspondingly, SLW genes are specifically induced or suppressed by SLWF, but not by SPWF feeding. We found 1 of the two SLW genes was induced, while the other was suppressed. We are in the process of further analyzing the putative WDR and SLW genes by cross hybridization, cloning and sequence analysis.

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Research & Implementation Area: Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions.

Dates Covered by the Report: July 1996 - January 1997.

Feeding Behavior of Adult *Bemisia argentifolii* on Host and Non-Host Plants

The feeding behavior of adult *Bemisia argentifolii* on host and non-host plants is being studied using the electronic feeding monitor technique. Four plant species were used: lima bean which is a good host plant as well as the host plant on which the whiteflies were reared; broccoli which is a very good host plant, but the whiteflies used in these experiments had never encountered broccoli prior to initiation of the experiments; corn which is an occasional host of the whitefly, but had not bee encountered by the whiteflies prior to the experiments; and sugar beet which is a non-host of *B. argentifolii* and also had not been encountered by the whiteflies prior to the experiments. Thus, the whiteflies were studies on a good host with which they were experienced (lima bean), and three plants with which they were inexperienced: a good host (broccoli), an occasional host (corn), and a non-host (sugar beet). Each replicate consisted of a six-hour recording of behavior of the whiteflies beginning at their initial contact with the test plant. Presently, only about 9 replicates per plant species have been completed, and the goal is to complete 25-30 replicates per plant species; thus this report presents only preliminary results.

Whiteflies penetrate the plant with their stylets primarily in an intercellular route; weaving their stylets between plant cells on their way to their primary feeding site, phloem sieve elements. The average amount of time per 6-hour recording period that was occupied by phloem ingestion was significantly greater for whiteflies on the familiar host plant, lima bean (2.52 ± 1.92 hour; mean $\pm$ S.D.), than for whiteflies on broccoli (0.60 ± 1.21 h), corn (0.84 ± 1.12 h), and sugar beet (0.18 ± 0.17). A closer look at the data revealed that these differences among plants in phloem ingestion time was due more to differences among plants in the proportion of whiteflies that attained phloem ingestion rather than due to differences among plants in the time spent in phloem ingestion for those whiteflies that attained phloem ingestion. Nine out of nine whiteflies tested on lima bean successfully reached and ingested from phloem are taken into consideration on the four plant species, then there was little difference among plant species in variables related to phloem ingestion, such as time to first phloem ingestion (however, sample sizes are presently too small for reliable statistical testing). The number of times that the stylets were partially retracted and re-directed during stylet penetration did not differ significantly among plant species, and averaged about 0.31 times per 10-min of stylet penetration time. This result combined with the apparent lack of differences among plant species in the time required to reach the phloem suggest that the whiteflies were able to locate phloem sieve elements with similar ease on all four plants. Additionally, once the phloem was reached, the total duration of phloem ingestion appeared to be similar among lima bean, broccoli, and corn; but may be shorter on the non-host, sugar beet. Thus, summarizing the phloem ingestion data, the average amount of time that the whiteflies were engaged in phloem ingestion was significantly greater on lima bean than on the other three plant species. For broccoli and corn, the lower average duration of phloem ingestion appeared to be due to fewer whiteflies successfully reaching the phloem; for those whiteflies that did reach the phloem on broccoli and corn, they reached the phloem and ingested from phloem in similar amounts of time as on lima bean. For the non-host, sugar beet, the lower average duration of phloem ingestion appeared to be due to both a lower proportion of whiteflies successfully reaching the phloem, and for those whiteflies that did reach the phloem, a shorter duration of phloem ingestion. Time required to reach the phloem did not appear to differ between sugar beet and lima bean. Larger sample sizes are required before definitive conclusions can be drawn.

Whiteflies laid eggs on all plant species, but the numbers of eggs were significantly greater on lima bean and broccoli than on corn and sugar beet. Interestingly, on the unfamiliar plants (broccoli, corn and sugar beet), 90-100% of the eggs were laid before any phloem ingestion took place. Thus, the whiteflies were committing their progeny to a plant based on cues perceived before phloem ingestion. Furthermore, 55-100% of the eggs laid on unfamiliar plants were laid during stylet penetration before the whiteflies made any intracellular punctures, indicating that they oviposited in response to cues perceived on the leaf surface and/or intercellular spaces within the leaf.

TABLE B. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section B: Fundamental Research—Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus-Vector Interactions

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
B.1 Studies of feeding behavior: sensory receptors, ultrastructure, morphology, digestive physiology; intra- and interspecific competition.	Year 5: Continue basic research; investigate approaches for interrupting feeding and digestion, and reducing competitive abilities.	X		Adults and nymphs secrete a stylet sheath that is attached to a vascular bundle in leaves. The abundance of vascular bundles in various plant cultivars and species is correlated with abundance and success of nymphs. Nymphs target only minor vascular bundles, and stylets of surviving nymphs always reach bundles and phloem cells within. Lower surfaces of the youngest leaves of most plant species tested are preferentially selected by adults, and feeding is concentrated in areas containing vascular bundles. Adult whiteflies prefer sites where vascular bundles are closer to the leaf surface, adding additional credence to the observation that the under surface of the leaf is the optimal ecological niche for *B. tabaci.*
B.2 Studies of biochemistry, physiology, nutrition, development and reproduction, genetics and genetic diversity.	Year 5: Continue basic studies; implement strategies for interfering with key processes; assess potential for further development.	X		Artificial feeding systems were established to evaluate effects of chemical, toxins, and antibiotics on whitefly fecundity, development, and honeydew production, and to study feeding behavior, relative to intake of phloem sap and geminiviruses in phloem sap. One feeding chamber experiment tested semi-synthetic diet presented through a Parafilm membrane and demonstrated an ability to rear whiteflies successfully from egg to adult. Egg hatching rates were 2-50%, and specific dietary constituents were critical to development past third instar. Feeding behavior of immatures was studied using ingestion of fluorescent markers, and feeding structures active during ingestion and processing were video-recorded. Constituents of phloem sap ingested by whiteflies and composition of honeydew were studied; certain amino acids in phloem sap were in reduced forms, suggesting host amino acids are metabolized in whiteflies.
B.3 Studies to discover and analyze diagnostic characteristics of SLWF, including component taxa, and to determine biological and genetic basis for development of biotypes, host races, and species.	Year 5: Provide synthesis of diagnostic analysis of SLWF taxa; relate results to other fundamental approaches; continue molecular identification services; finish development of rapid identification system.	X		Three whitefly complexes in the genus *Bemisia* have been defined based on classical taxonomic criteria is tentatively corroborated with molecular sequence data. The *B. tabaci* species complex contains those *Bemisia* populations that are of economic importance in agroecosystems as pests and whitefly vectors, and includes the type *B. tabaci* (1989), the silverleaf whitefly, and other *B. tabaci*-like individuals based on classical morphological criteria. Molecular markers are under investigation for inference of phylogenies that can be compared to those predicted by morphometric and other

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
B.4 Develop systematic analysis of the genus *Bemisia* utilizing various methods.	Year 5: Complete systematic analyses; validate supplementary methodologies.	X		Morphological studies for taxonomic considerations of the A and B biotypes focused on the pupal vasiform orifice, and mapping of setae and pore arrangements. Morphometric analysis of data produced such widely scattered loci that the two strains could not be separated. The submarginal setae, ASMS4, present in the A biotype, in type material *Bemisia tabaci* from Greece, and in type material *Bemisia poinsettia,* is absent from the B biotype 95% of the time. Because the character is not present or absent 100% of the time, the ASMS4 setae are minute, and their expression are affected by environment, it will not be useful as a taxonomic character for differentiating the A and B biotypes, or for recognizing sibling species within the proposed *Bemisia tabaci* species complex. A 550 bp sequence of whitefly 16S ribosomal mt RNA gene show promise as an informative molecular marker, based upon phylogenies inferred from several trial datasets. The B biotype, or silverleaf whitefly, clusters with other Old World whitefly sequences in a consensus tree derived from 100 bootstrap samples of rDNA sequences, suggesting the silverleaf whitefly is of Old World origin. This whitefly mt gene marker will be assessed for utility in corroborating relationships by RAPDs patterns for two parasitoids of *B. tabaci.*
B.5 Identify and define SLWF toxicogenic effects. Develop dsRNA and cDNA probe.	Year 5: Define mechanisms of plant resistance and integrate knowledge in developing IPM.	X		Direct toxicogenic effects of the B biotype are expressed as uneven ripening in tomato, silverleaf in squash, stem streaking and thickening in *Brassica*, and paleness of leaves in lettuce and other composites. Pathogenesis-related proteins are typically sequestered in vacuoles or transported out of cells into the intercellular fluid (IF). The IF from silvered leaves of B biotype-infested cucurbits contained induced proteins of 31K and 70K Mr, whereas a characteristically prominent constitutively expressed protein (60K) was shown to be absent.
B.6 Characterize silverleaf whitefly endosymbiote (SWFe) influence on metabolism, host range, and biotype formation.	Year 5: Analyze progress and determine feasibility of pest management based on interruption of endosymbiotic relation.	X		Mycetome-like organs containing prokaryotic-like and pleomorphic micro-organisms were observed in immature instars, and at the distal tip of each egg. Transfer of endosymbionts in mycetocytes from the female to developing ova is a process that occurs continuously, prior to oviposition. Mycetocyte-containing bacteria were observed in oocytes inside a common membrane in the region that becomes the pedicel end of the egg. In the final stages of ovum development, the plasma of the oocyte completely surrounds the mycetocyte and the chorion thickens. Ooctyes with mycetocytes were present in adult females 16 hr after emergence, and none were observed in individuals that were less than 2 hrs old. Antibiotics known to have a negative impact on prokaryotic processes and metabolism were detrimental to whiteflies, whereas whiteflies appeared to be unaffected by those specifically inhibiting prokaryotic cell membrane synthesis or affecting cell walls. Negative effects are attributed to mortality of the primary endosymbiont in whiteflies. Partial curing of adults resulted in a reduced vigor of offspring of treated adults, and lowered intensity of phytotoxic silvering of squash leaves.

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
B.7 Investigate etiology of diseases; biological and molecular characterization of causal agents; develop understanding of relationship; molecular probes for viral diseases; diagnostics and resistance; virus-vector specificity and interactions.	Year 5: Continue virus-vector studies; evaluate resistance studies: engineered and classified w/prototype isolates. Continue biological and molecular studies of new pathogens; viral taxonomy; standard-ize names.	X		Diseases of vegetable and ornamental crops caused by the WFT or subgroup III members of the Geminiviridae were reported in Arizona, Florida, Texas, and throughout the Caribbean Basin and Mexico. In Arizona, molecular cloning and characterization were the focus for isolates of cotton leaf crumple, squash leaf curl, and an uncharacterized geminivirus of Solanaceae. Studies were initiated to identify geminiviruses of cotton, kenaf, pepper, squash, tomato, tomatillo, watermelon, and weed species in Texas, and to determine the epidemiology of squash leaf curl in cucurbits. Studies in Florida concentrated on determining experimental and natural host ranges and identification of sources of inoculum for tomato mottle virus. TMoV infects species within the Solanaceae and Leguminosae, and that the most important source of TMoV inoculum is infected tomato fields. TMoV has been cloned and sequenced and has been shown to be related to other New World bipartite WFT geminiviruses. Breeding for virus resistance/tolerance in tomato was initiated with *Lycopersicon chilense* as a potential source of resistance gene(s). Engineered pathogen-derived resistance approaches have made promising strides using expression of mutant *CP*, *BC1*, and *Rep*. An epidemic in bean caused by Macroptilium mosaic geminivirus were reported in Florida for the first time. a recently introduced strain of bean golden mosaic virus from the Caribbean Basin and is distinct from the BGMV-FL strain. A strain of TYLCV, nearly identical to TYLCV-Israel, was found for the first time in The Dominican Republic, Jamaica, and Cuba. Lettuce chlorosis disease, caused by a new closterovirus, was documented in several vegetable crops in southern California. This virus is now known to be phloem-limited, can be transmitted by the A and B biotypes of *B. tabaci*, and has narrow host range that does not include cucurbits. A new WFT closterovirus, tomato infectious chlorosis (TICV) was discovered in coastal California tomato greenhouses and is transmitted by the greenhouse whitefly, but not *B. tabaci*. The virus was also identified in tomato greenhouses in Italy.

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
B.8 Study epidemiological parameters: vector population dynamics; disease thresholds; identify sources of inoculum, distribution, severity, and prevalence of pathogens. Correlate efficiency of transmission with biotypes, diversity and parameters of cropping systems.	Year 5: Continue development, application of management strategies based on epidemiology studies. Transfer information for use in cropping systems, host free periods, recommenda-tions for long term disease management.	X		A PCR technique was developed for universal detection of WFT geminiviruses. PCR primers target the core region (nts 494-1048) of the capsid protein gene, the most highly conserved gene among subgroup III viruses. PCR products of diagnostic 550bp size indicate positive infection. Fragments are cloned and DNA sequences obtained to verify identity with sequences from well characterized viruses. A collection of core coat protein gene sequences has been established in a database. This database will be useful for geminivirus identification, molecular epidemiological studies, and for making predictions about phylogenetic relationships between geminivirus isolates. Among isolates collected and analyzed from New World sites, all but one virus, now known to be introduced into the Caribbean Basin from the Eastern Hemisphere, cluster with New World viruses. This suggests that the majority of viruses problematic in the US, Mexico, and Caribbean Basin originated in the New World, and are not introduced viruses. Further, these data extends the hypothesis that recent epidemics in the New World are primarily the result of indigenous viruses that rarely reached epidemic status in the past due to mobilization by new whitefly biotypes and altered disease pressures. Cloning and sequence of a second key region of the genome, the common region, are underway for the same library of geminiviruses for identification and to provide a second molecular maker in a key region of viral genomes. Comparative analysis of core coat protein and common region sequences permitted delineation of (putative) genetically related subclusters within the WFT subgroup, and indicates a wider range of variability within the subgroup than previously thought. Ability to define WFT geminiviruses as constituents of particular genetic subclusters by key viral sequences will permit a better understanding of evolutionary relationships, permit early recognition of new and emerging viruses, and suggests a possible strategy for selecting a range of prototype isolates for classical breeding or engineered resistance efforts.
B.9 Study mating and oviposition behavior.	Year 5: Exploit such factors in field trials to determine their potential in control methodology; quantify role of oviposition behavior in population dynamics.	X		Studies of mating behavior and effects of mating on fecundity, viability, and population structure of whitefly on cotton indicate distinct behaviors for the B biotype and other whitefly genera. Whitefly are haplo-diploid and exhibit arrhenotoky, though in whiteflies, this area has not been formally studied. Viability of eggs can be much lower from an unfertilized female. Oviposition rate during the first days of adult life is not influenced by mating history. Mating behaviors for three whitefly species were captured on film using a video recorder attached to a binocular microscope. Leaf age and position on the plant influenced oviposition rates. Differences in behavioral patterns and temporal modulation of activities were documented during courtship and copulation. Elucidating behaviors, cues, and barriers will facilitate an understanding of mating behaviors between males and females within the *B. tabaci*. complex. The basis for apparent reproductive isolation between certain populations of *B. tabaci* is not known, and has been another major confounding factor in resolving the taxonomic status of *B. tabaci*.

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
B.10 Determine factors influencing host plant selection and host acceptance.	Year 5: Determine potential for manipulating semiochemicals and other host-finding or acceptance cues as behavioral components in SLWF control systems.	X		*B. tabaci* is strongly attracted to surfaces reflecting in yellow-green wavelengths at certain times and to blue/UV reflecting surfaces at others. Host acceptance or rejection seems to be largely due to taste response following short leaf probing in the mesophyll. Influence of host and host choice on whitefly fecundity was examined, and at times, eggs were deposited on plants suitable for adult feeding that were not conducive to progeny survival. AC feeding monitors were applied to correlate ovipositional activity with adult feeding patterns, and patterns of females are thought to be more indicative of ovipositional site preferences than of adult nutrition.
B.11 Identify plant nutritional and defensive responses to SLWF and their effects on SLWF and natural enemies.	Year 5: Target specific factors for genetic engineering of plant resistance.	X		In cucurbits, several natural products (alpha-tocopherol, squalene, and linolenic acid) were analyzed in developing leaves after whiteflies fed on lower leaves. Quantitative changes in these lipids may have nutritional consequences for the whitefly and/-physiological implications for the host plant. Linolenic acid and alpha-tocopherol (vitamin A) may induce host defensive responses and serve as vitamins for whiteflies, while squalene is a precursor of sterols which serve as critical structural components of plant cells and are also required by insects. Studies of protein expression in tomato indicated that several proteins were induced by adult and larval feeding. Though total leaf activities of chitinase, peroxidase, beta-1,3-glucanase, and chitosanase were greater than for controls; two proteins induced within 24 h were identified as chitinase and glucanase.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: July - October 1996.

Insecticide Resistance Management: Strategies of Using IGRs vs. Pyrethroids for Initial Applications Against Silverleaf Whitefly

We conducted a ground application experiment with objectives of determining if 1) control is more efficient if pyrethroids are used first, then followed by insect growth regulators (IGR) or vice versa, 2) what effects do pyrethroid first sequences vs IGRs first sequences have on resistance management, and 3) will a more efficient ground spray result in significantly higher yields. This experiment was conducted at the University of Arizona, Maricopa Agricultural Center, Maricopa, AZ. The experimental factorial was 2 x 2 x 3 replicates. The first two factorials were 1) 2 chemical sequences, a. IGRs (Applaud then Knack) at first followed by pyrethroids, and b. Pyrethroids first followed by IGRs (Applaud then Knack) and 2) 2 pressures, 225 psi, and 40 psi., both at 15 gal./ac; the boom was designed for more efficient under leaf coverage by having drops and swivel nozzles. Replicates 1 and 2 were SG 259 and replicate 3, DP 5415. Planting was on a 6-plant/2-skip row with an actual plant of 45 ac. There were 12 plots of 3.3 ac each for a total of 45 ac of land actually planted and 60 ac occupied. An additional 20 ac in the same 2 fields as the experimental plots were treated at the same time to insure integrity of the experiment.

Over a 12 week sampling period, the following statements can be made. For eggs, by week 3, twice as many eggs (approximately 8000 per 3.88 sq. cm) were present in IGR first plots sprayed at 40 psi than in the other treatments. By week 6, continuing through week 9, all treatments were approximately the same. However, for weeks 10-12, pyrethroid first treatments had twice as many eggs as the IGR first plots. The highest number of eggs at the end of the trials was approximately 2000 per 3.88 sq. cm. for pyrethroid first plots sprayed at 40 psi. Large nymphs peaked at week 2 with highest numbers (approximately 330-450 per 3.88 cm sq.) in pyrethroid first plots. IGR first plots treated at 225 psi had approximately 200 large nymphs compared with greater than 300 large nymphs for the plots treated at 40 psi.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: July-October 1996.

Natural and Sucrose Esters as Biorational Insecticides in Field Trials Against the Silverleaf Whitefly Be*misia argentifolii*

Two trials were conducted. In the first, comparisons were made between an extract of a natural acyl sugar ester extracted from *Nicotiana trigonophalla* and 2 concentration of a synthetic one, OTC8SE; concentration expressed as percent volume. In 1995 tests, this chain was the most effective synthetic sugar ester of those tested at a concentrations of 0.3%. Here we report on trials with it at 0.45 and 0.60%. The test with the natural sugar extract was at 0.3%. Plot trials (0.15 ac/plot, 3 replicates, random block design) were conducted at the Maricopa Agricultural Center, U of A, Maricopa Arizona in 1996 against the silverleaf whitefly, *Bemisia argentifolii*. Six treatments were applied 6 times at weekly intervals. Treatments included embedded controls, an additional untreated check block of 1.5 acres, and a pymetrozine/fenoxycarb treatment used as an efficacy standard. Concentrationsare expressed as percent volume for acyl sugars and extracts or ai/acre for pymetrozine/fenoxycarb. Treatments included the adjuvant, Kinetic™. Applications were by ground at 15 gal./ac at 225 PSI via drops that sprayed upward. Efficacies were expressed as percent reduction in whiteflies from the block control. The number of silverleaf whiteflies was relatively low throughout the season. However, mean no. of eggs per 3.88 sq. cm ranged from 136.7 to 52.1 and were not significantly different from one another but approached significance at F equals 0.07. Similarly, large nymphs ranged from 16.0 to 0.4 and were not significantly different from one another.

A second trial was conducted at the end of the season after the silverleaf whitefly population had increased considerably. A test was completed on much smaller plots (0.067ac/3plots), replicated by 3 in a random block design of O T C 8 S E, a natural acyl sugar ester extracted from *Nicotiana trigonophalla*, and an extract of a polyploid *Nicotiana gossypii*, all at 0.3%. The sprays were applied by hand at 30 gal./ac at 20 psi. Mean no. of eggs per 3.88 sq. cm ranged from 480.9 to 519.4 for the two extracts and the controls. However, the synthetic sugar ester had a mean of 298.7 eggs and the pymetrozine/fenoxycarb had 271.1; these were significantly different from the former at P = 0.05%. Results for large nymphs showed significance for the active agents with these of 26.93 for pymetrozine/fenoxycarb to 31.73 for an extract of *Nicotiana gossei* compared to 71.5 and 54.7 for two controls; these differences for the two groups were significant at P = 0.05.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1995 - 96.

Insecticide Resistance Differences in Whiteflies from Four Regions: Agricultural, Operational, and Ecological Components

Management of *Bemisia tabaci* (type B) in the southwest USA and northern Baja California has improved tremendously in the years following the first destructive outbreaks. This is a significant achievement in that many of the agricultural production areas in this region represent optimal environments for explosive growth of *B. tabaci* populations. They feature overlapping seasons planted with vast areas of highly suitable host crops and a climate with mild winters, phantom rainfall, and long, hot summers that drive generation times to periods of 2.5-3 weeks for 5-6 consecutive months. Outbreaks such as those that occurred in Imperial Valley in '91-'92 and in Arizona and Mexicali in '92 stand as testaments to the brute-force potential of *B. tabaci* in these embracive environments. The same settings and basic ingredients for destruction are still in place, but the difference between then and now is that management and research experience has taught the necessity for early and constant vigilance against whitefly infestations, and that we have more potent and effective chemicals for combating infestations. For example, in the Imperial Valley, the entire dimension of the annual population cycle has been greatly diminished with the availability of imidacloprid for use in spring melons. No longer are whitefly populations jump-started on 15,000 acres of spring melons, cycling through multiple generations into a marauding mass that spills over into virtually every field and backyard throughout the valley. Instead, formation of the early critical mass has been seriously impaired by imidacloprid, and consequently all other conventional insecticides have gained a relative measure of power by being released from constant use pressure.

Many of these chemicals have been in continuous service since the initial outbreaks, being registered for use on multiple crops and relied upon year-round, and yet are still performing effectively in the Imperial Valley and elsewhere. However, there are regions such as central Arizona where resistance levels to certain insecticides have increased and field control diminished. Evidence of differences among regional whitefly populations prompted us to pursue a study that would first identify the relative responses of whiteflies from different regions to various insecticides, and then examine certain characteristics of these regions with respect to what they contribute to resistance dynamics. Whiteflies from four distinct regions were surveyed over a two year period, including central Arizona, Yuma, Imperial, and Mexicali. Information from the same regions is currently being collected according to the following outline:

A. Agricultural Component--Whitefly Production Area
   1. Cultivated Crops
      - types and relative acreages
      - whitefly output per crop
   2. Non-crop Hosts
      - whitefly sources relative to crop contributions

B. Operational Component--Insecticide Pressure per Host Crop Area
   1. Total lbs. A.I. (each compound and class)/acre
   2. Frequency and Timing of Applications
   3. Use Patterns (i.e. mixtures, rotations)

C. Ecological Component--Whitefly Biology and Behavior
   1. Generations per Crop Cycle
   2. Gene flow between fields and crops (with respect to insecticide use)

We might expect that circumstances for many of the above categories would be mostly similar among regions. For instance, the types of insecticides used, timing of applications etc. should not vary a lot, nor should the behavior of whiteflies. The most important factor might be summed up as the quantity of insecticide deposition per unit area within the overall whitefly activity zone, what portion of this zone serves as insecticide refugia, and the relative whitefly outputs in both areas and degree of flow in between.

Investigator's Name(s): C. C. Chu, M. A. Boykin, C. G. Jackson, and T. J. Henneberry.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

EXP 80667A - An Experimental Systemic Insecticide for Silverleaf Whitefly Control on Cotton

Results of studies conducted in Imperial Valley, California, in 1996 showed that foliar applications of an experimental systemic insecticide EXP 80667 to cotton reduced silverleaf whitefly densities cotton season long. Lint yields from plots treated with EXP 80667 at 0.075 lb/ac was comparable to lint yields from plots treated with registered and recommended insecticide and an insecticide mixture and significantly greater than yields from untreated control plots.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Dyne-Amic Increased the Efficacy of EXP 80667A Against Silverleaf Whiteflies on Cotton

Studies conducted in Imperial Valley, California, in 1996 showed that the addition of 4 ounces per acre of Dyne-Amic (Helena Chem. Co., Memphis, TN), a blend of organosilicone and methylated seed oil, increased efficacy of an experimental systemic insecticide EXP 80667 for silverleaf whitefly control. With added Dyne-Amic, the rate of EXP 80667 insecticide could be reduced from 0.075 lb to 0.05 lb ai/ac without reducing yield.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Suitability of *Bemisia argentifolii* Reared on Artificial Diet as Hosts for Parasitoids

Biological control of *Bemisia argentifolii* by augmentative methods is currently hindered by the lack of an artificial rearing system for the host. The recent development of an artificial rearing system for *B. argentifolii* (Jancovich et al, 1997) opens the possibility for rearing parasitoids without the host plant. We have demonstrated that at least one parasitoid species can be reared to adult on *B. argentifolii* nymphs in artificial culture.

Mated *Encarsia pergandiella* females from south Texas were introduced into feeders on which *B. argentifolii* had developed to second, third and fourth instar. Foraging and oviposition behavior of the parasitoids appeared normal. Essentially all viable *B. argentifolii* nymphs were parasitized. The first adult parasitoids emerged within 19 days at 25-27 °C.

Similar experiments with *Eretmocerus* sp. from Texas demonstrated typical foraging behavior and attempted oviposition. However oviposition was unsuccessful as the females appeared to be unable to insert the ovipositor beneath the host.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Large Scale Evaluation of Insect Growth Regulators for Whitefly Control

Two insect growth regulators (IGRs) that are selective against whiteflies, Knack® (pyriproxyfen) and Applaud®, (buprofezin), became available for the first time in 1996 to Arizona cotton growers under emergency exemption. These IGRs were studied in a commercial-scale whitefly management trial (178 acres) in 1996. The trial was designed to evaluate provisional whitefly recommendations. Three sets of factors were tested in a 48 plot factorial design: application methods, thresholds for initiating IGR use, and insecticide regimes.

Ground (broadcast at 15 gallons/acre) and aerial applications (5 gallons/acre) were roughly equivalent over a wide range of variables examined (whitefly populations, number of sprays, cost, and yield). Under the higher population densities, ground applications sometimes suppressed whiteflies to a greater extent than aerial applications. The rapid advance of the population resulted in the initial triggering of all thresholds within just five days. No consistent trend in population suppression was seen for the thresholds tested (0.5, 1.0 and 1.5 large, visible nymphs per 3.88 sq cm leaf disk located between the major and first, left lateral vein of the fifth main stem node leaf below the terminal). The control cost for the highest threshold was significantly less than for the middle threshold, but not for the lower threshold.

Under emergency exemption, each IGR may be used only once per season. The sequence of use did not result in any consistent advantage in population suppression, cost, number of sprays needed, or yield. The IGR regimes were in general more efficacious, less disruptive, and less costly than the conventional insecticide regime. There were significantly fewer sprays needed by the IGR regimes compared to the conventional regime. All regimes successfully controlled whitefly populations for a 12 week period and cost significantly less than conventional programs tested in 1995 (Ellsworth et al. 1996a). IGRs are effective, long-lasting, and less environmentally disruptive alternatives to conventional insecticides. They reduce the risk of secondary pest outbreaks and pest resistance, and increase the opportunity of natural enemy conservation.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: August 28, 1996 - October 23, 1996.

A Demonstration on the Effectiveness of 1% Detur for Controlling WF Pupae on Containerized Hibiscus

A small plot of 1 gallon Hibiscus rosa sinensis received weekly applications with a hydraulic spray rig using a 1% solution of Detur. WF pupae numbers were reduced from 35 per 25 leaves sampled to zero in 2 weeks on the treated plot. WF pupae numbers on the untreated plot were 45 per 25 leaves sampled at the precount and 30, 2 weeks later. There appears to be some residual activity with Detur. The WF pupae counts a day before the last application, and for each 7 day scouting intervals were as follows: treated and untreated respectively , (pc) 1 and 10, (7 day) 0 and 30, (14 day) 0 and 6, (21 day) 2 and 10.

A demonstration on 25,000 and 12,000 sq.ft. 3 gallon Hibiscus yielded a 73% reduction in 2 weeks and 97% and 98% reductions respectively in 3 weeks. Again this was a 1% solution of Detur on approximately 7 day intervals. Detur performed very well against WF in a commercial nursery during peak WF season.

Investigator's Name(s): T. J. Henneberry[1], L. Forlow Jech[1], D. L. Hendrix[1], H. H. Perkins, Jr.[2], and Don Brushwood[2].

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: January 1, 1996 - December 31, 1996.

Silverleaf Whiteflies, Cotton Stickiness, and Yields in Long and Short Staple Cottons

Bemisia spp. infestations in cotton often result in honeydew deposits on lint of open cotton, *Gossypium* spp., bolls. The honeydew remains localized causing sticky cotton that adheres to machinery surfaces during harvest, ginning, and lint processing . The cotton lint stickiness problem has increased with increasing *Bemisia* population development and spread and is of most concern at the textile mill. We conducted studies to define *B. argentifolii* population development on long- and short-staple cotton cultivars and determine the influence of plant density and insecticides on whitefly populations, sticky cotton and cotton yields. We also compared cotton lint stickiness and lint yields for different methods of seed cotton sampling. Cotton plant densities of 10 or 40 thousand plants/acre had no effect on numbers of silverleaf whitefly adults, eggs, nymphs, extracted sugars from lint samples or thermodetector sticky cotton counts. Higher numbers of whiteflies occurred in early-season in Pima S-7 cotton than in DPL 50 or DPL 5415 cotton. Seasonal averages for sugars, percentages of total reducing sugars and thermodetector counts were higher for DPL 50 compared with Pima S-7 but not DPL 5415. The first open cotton bolls subject to honeydew contamination occurred between 17 and 22 August. Most of the sugar analyzed from lint samples occurred during a 24 day period from 22 August to 15 September for all cultivars harvested 25 September. DPL 50 and DPL 5415 had 99 and 91% of the bolls open during 22 August to 25 September as compared to 76% for Pima S-7 resulting in lower sticky cotton counts for Pima S-7 compared with DPL 50 but not DPL 5415. Insecticide treatments reduced thermodetector counts and associated sugars extracted from lint. Sticky cotton results for 20 boll randomly picked samples were comparable with results from total open cotton/plant harvests but both sample methods gave significantly lower individual sugar, percentage of total reducing sugars and thermodetector counts compared with machine total cotton plot harvests. DPL 50 and DPL 5415 produced significantly more cotton than Pima S-7. Higher lint yields occurred in plots planted at 40,000 plants per acre compared with 10,000 plants per acre. Highest cotton harvests were obtained by hand picking all open bolls from all plants in 13.1 foot of row weekly as compared to a single 13.1 foot of row pick on 13 September and machine picking (spindle) on 25 September.

Investigator's Name (s): Stefan T. Jaronski[1], Joanna Rosinska[1], Chris Brown[2], Ruth Osterlind[2], Robert Staten[2], Richard Craft[3], and Larry Antilla[3].

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: July 1996.

Impact of *Beauveria bassiana* Mycotech Strain GHA, Buprofezin, and Pyriproxygen on Whitefly Predators in Arizona Cotton

Single 0.4 hectare plots of Bollgard® cotton in Scottsdale, AZ were treated with either *Beauveria bassiana* Strain GHA (Mycotrol® WP, 2.24 Kg, 9.9 x 1013 conidia, per hectare), buprofezin (Applaud®, 280g a.i./ha), or pyriproxyfen (Knack®, 25 g a.i./ha) on July 30, 1996. A fourth plot was left as an untreated control. Plots, 137 meters by 30 rows on 1 m centers, had the two center rows removed to serve as a spray road for a truck-mounted ACRPC lateral mist blower. *B. bassiana* was applied at 234 L/ha; the two chemicals at 187 L/ha. No other insecticides were applied prior to the trial. The plots were sampled seven days post-treatment to assess nymphal *Bemisia argentifolii* populations, using the fifth main leaf, with six groups of 10 leaves per treatment. Nymphs were counted in each of two 4.15 cm2 discs cut from either side of the main vein. Predaceous insect populations were sampled with a D-Vac system on August 3, 7, and 10 and frozen. Samples consisted of four groups of 25 plants each, per treatment. Predators in these samples were tabulated by species. All or most of the insects (depending upon sample size) in the August 3 and 7 collections were incubated on *Beauveria*-selective media for 48-72 hours and then inspected for sporulating fungus.

One week after treatment, whitefly populations were reduced by 80% (*B. bassiana*), 0% (buprofezin, or 70% (pyriproxyfen), relative to the untreated control. Mean number of whitefly nymphs in the untreated plot was 2.16 (± 0.13). Control by the fungus and pyriproxyfen were significantly different from the control (Tukey's HSD Test, $p = .05$). Collected predators consisted of reduviids, Nabis sp., Orius sp., Geocoris sp., Collops sp., coccinellids, and chrysopids. Chrysopids and Orius were the most numerous, ranging from 42-102 and 35-157 insects per 100 plants, resp. No samples showed significant treatment effects. *B. bassiana* was present in all predator species, in all treatments, including the untreated control, which was 111 meters from the fungus-treated plot. Prevalence levels of *B. bassiana* ranged from 0 to 37% in samples of greater than 10 insects. There were no clear trends in fungal prevalence associated with treatment. Presence of the fungus in the non-*Beauveria* treated plots suggests endemic *Beauveria*; no attempts were made to identify the recovered fungus as strain GHA.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Deposition of Tracer Dye on Paper Labels for Evaluation of Spray Coverage

The two types of self-adhering paper microscope slide labels were tested: a standard microscopic slide labels 22 x 22 mm (Fisher #11-863) and a thick slide label 23 x 23 mm (Shamrock, Bellwood, IL). The tracer used was a blue dye (FD&C No. 1, Warner-Jenkinson, St. Louis, MO) diluted to 1000 ppm plus a non-ionic surfactant (APSA-80) added at the recommended rate of 0.05% (vol./vol.). Spray was applied through a chain-driven moving boom driven by a variable speed D.C. motor and supplied by an electrically powered piston pump. The boom was equipped with two drop lines, each holding two Albuz ATR hollow cone ceramic nozzles, flanking the median line of a 30 ft table. Plants (n =20), a compact tomato variety ('Lanai'), were 50-60 cm tall and placed on the median line of the spray table. For the first repeated twice, two types nozzles (red, 0.24 mm orifice and brown, 0.08 mm orifice) were tested and labels were placed at two canopy locations (outside and inside), and two leaf surfaces (upper and lower). Delivery rates were of 68.4 gal/ac for red nozzles and 23.4 gal/ac for brown nozzles. Four thicker and 4 thinner paper squares and 4 leaf squares were randomly placed on a sheet of paper. Blue dye was sprayed using a plastic Spritzer. After the sprays dried, labels and equal-sized leaf squares were placed in separate plastic vials in which 10 ml of water was added. Two labels were used at each position for the second repetition and one label from each position placed in 70% EtOH for comparison. Labels, leaf squares or whole leaf were placed in 10 ml of water, shaken for 30 m and optical density measured with a Perkin-Elmer Lambda 6 UV/VIS spectrophotometer to estimate dye concentration. In another experiment, recovery of blue dye was compared from paper squares, leaf squares, and whole leaves of potted rough lemon seedlings (≈70 cm high, n = 20). Two leaves in the middle of the plant were randomly selected, and a thick label placed on the upper surface of one leaf, and the lower surface of a second leaf. Nozzles were yellow Albuz ATR hollow cone, pressure 100 psi and delivery rate 37.2 gal/ac. Upon drying, the leaf was cut around the paper square, and the paper square and the leaf squares were separated. In another experiment, dye on paper squares was compared to the coverage on water-sensitive yellow squares using 2 types of sprayers, a tractor drawn boom hydraulic sprayer and a Berthoud sprayer. The hydraulic sprayer had a pressure of 200 psi and a delivery rate of 69 gal/ac at 2 mph. The Berthoud operated at 50 psi with a delivery rate of 26 gal/ac. Yellow Albuz hollow cone nozzles were used for the hydraulic sprayer, and brown Albuz hollow cone nozzles for the Berthoud sprayer. For each sprayer, 3 leaves were randomly selected, one from the top, middle and bottom, from each of 20 tomato plants (50 cm high, 10-12 node). Yellow water-sensitive cards and paper squares were placed on the upper and lower leaf surfaces of the same selected leaf. In the first test, red nozzles delivered significantly more blue dye on paper squares than brown nozzles, and significantly more on the upper surface than on lower surface with brown nozzles. Paper squares from inside the plant canopy had more on the upper surface with both kinds of nozzles. In the 2nd test, blue dye recovered from both thickness of the self-adhering paper squares, standard paper squares, and leaf squares were slightly greater for the 70% EOH but not significantly different from water. The leaf square rinsate had the least amount of dye. In the 3rd test, greatest amount of blue dye per cm^2 was recovered from the paper squares on the upper leaf surface, followed by the leaf squares with the whole leaf wash-off showing the least. On the lower leaf surface a similar amount of blue dye per cm^2 was measured on paper squares, leaf squares and the whole leaf. In the fourth test, blue dye recovered on the paper squares and coverage (ranks) on the yellow water-sensitive papers differed significantly between the 2 sprayers. After the adjustment, the dye recovered from the upper leaf surfaces was not significantly different between the two sprayers with one exception, while the dye on lower leaf surface delivered by the Berthoud sprayer became significantly greater than that delivered by the hydraulic sprayer, implying that the Berthoud sprayer improved the deposition on lower leaf surface. Dye recovered on the paper squares and coverage on the water-sensitive paper cards was correlated when comparing the same locations. The correlation coefficient (r) at the same plant locations between the paper squares and water-sensitive paper cards was 0.74 for the hydraulic sprayer, and 0.72 for the Berthoud sprayer.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Insecticidal Effects of Surfactants on *Bemisia argentifolii*

Surfactants used were Silwet L-77 (100% silicone-polyester copolymer; Loveland Industries, Inc., Greeley, CO), Cide-Kick (A spray adjuvant for herbicide, 100% d'Limonene and selected emulsifiers; JLB International Chem. Inc., Vero Beach, FL), APSA-80 (80% alkyl aryl alkoxylate, free fatty acids, 20% inert ingredient; Amway Co., Ada, MI), and water as a control. Concentrations were: 0.1, 0.05, and 0.025% (vol./vol.). *Bemisia argentifolii* was cultured in an air-conditioned greenhouse on potted tomato and collard using Metro-Mix 300 growing medium. Plants were watered with 0.4% (wt.:vol.) of Stern's Miracle-Gro (an all purpose water soluble plant food with N-P-K: 15-30-15) once per week. Whitefly-free tomato plants (approximately 60 cm high, 7-9 nodes) were placed on a bench in a greenhouse. Whitefly egg-bearing plants were removed from the greenhouse, and whitefly adults were cleaned from the plants using a vacuum. Plants were confined in 60 x 60 x 60 cm large screen cages, and whitefly eggs were allowed to develop for 10 d to second and third instar nymphs. Tomato leaves bearing whitefly nymphs were dipped in surfactant solutions for 5 s, and air-dried for 1 h. Leaves were individually inserted into a 20-ml glass vial with water with petiole down. Vials were fixed on plastic trays using double sticky trap. The treated leaves were kept in an insectary with 25 ± 2°C, 60 ± 5% RH, and a photoperiod of 14:10 (L:D) h. The mortality of whitefly nymphs was recorded 3 d after treatment, and phytotoxicity was evaluated at the same time.

All 3 surfactants at 3 tested concentrations were effective against whitefly nymphs with 33.1-100% mortality. Silwet L-77 gave the greatest mortality, from 95.7% at 0.025% rate, to 100% at the rates of 0.05 and 0.1%. Affected whitefly nymphs were desiccated and separated from leaf surface 24 h after treatments, particularly in the treatments of Silwet L-77. All rates of Silwet L-77 except 0.25% caused severe phytotoxicity withe leaves desiccating by 24 h after treatment. Toxicity to tomato leaves was not observed with the low rate of Silwet L-77 or the other surfactants. Under the test conditions, these surfactants induced levels of mortality comparable to many conventional insecticides.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

IPM Actions and Practices in Cotton (3rd Year)

In 1994 and 1995 cotton growers were satisfied with silverleaf whitefly control and cotton yields. Only 3.5 insecticide applications during the season were required to control the insect pests complex (whitefly, lygus, pink bollworm, and leaf perforator).

Generally speaking, in 1996 whitefly control was appropriate in commercial fields that were planted on time, the insecticides were used when required and the practice of defoliation was made properly. However, the maximum infestation registered in commercial fields was 6 times higher in 1996 than in 1994 because of late plantings and because no insecticide was used when required nor was defoliation practiced.

The early silverleaf whitefly infestation was higher in 1996 compared to the previous two years due to the mild winter.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Rescate 200 (Acetamiprid) Performance Against Silverleaf Whitefly in Mexicali Valley, México

This new Rhone-Poulenc alternative to control Whitefly was evaluated on spring melon and cotton field trials during 1996. In both situations adult mortality and its effect over immature stages was better with Rescate 200 (50 and 100 gr a.i/ha) compared to the most common insecticides (Endosulfan, Provado, Capture, and Azana) or mixtures (Danitrol + Triazophos, Karate + Triazophos, and Azana + Triazophos) used in the region against the silverleaf whitefly.

Also, the amount of sootymold on leaves and open bolls was estimated lower in the experimental plots treated with Rescate.

In México this new insecticide does not have an official registration to be used in melons or cotton, only ornamentals (roses).

Investigator's Name(s): Eric T. Natwick[1] and Curtis E. Engle[2].

Affiliation & Location: [1]UC Cooperative Extension, Desert Research and Extension Center, Holtville, CA; and [2]Bayer Corp., Fresno, CA.

Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: September 1995 through October 1995.

Evaluation of Imidacloprid for Silverleaf Whitefly Control in Tomato Using Various Formulations and Application Methods

Fresh market tomato pelleted seeds with various rates of imidacloprid (Gaucho 480 FS) or pelleted without imidacloprid were sown at UC Desert Research & Extension Center 8 September 1995. Six insecticide treatments and an untreated control were replicated five times in a randomized complete design experiment. Insecticide treatments were as follows: Admire 2 F at 0.5 lb ai/ac, Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt, Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt followed by Provado 192 FL at 0.05 lb ai/ac, Gaucho 480 FS seed treatment at 1.51 lb ai/cwt, Gaucho 480 FS seed treatment at 3.49 lb ai/cwt, Gaucho 480 FS seed treatment at 4.99 lb ai/cwt. Admire 2 F treatments were injected one inch below the seedline prior to planting 8 September 1995. Gaucho 480 FS seed treatments of various rates were prepared by Gustafson, Inc., Plano, TX and sown into the appropriate plots. Provado 192 FL was applied as a foliar spray on 26 September 1995. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults on five seedling tomato plants at random from each plot on 19 & 25 September and 2 & 9 October 1995. Silverleaf whitefly nymphs were counted on 2.5 cm of leaf surface from five seedling tomato plants at random from each plot on 26 September and 2 & 9 October 1995. Plant height in cm were recorded for five seedling tomato plants at random from each plot on 25 September and 2 & 9 October 1995.

The numbers of adult whitefly among the imidacloprid treatments and the control were not different (ANOVA, $P \leq 0.05$) on 19 September. The Gaucho 480 FS seed treatments of various rates and the Admire 2 F treatment followed by Gaucho treated seed had significantly fewer whitefly adults than the control on 25 September, but the Admire 2 F treatment was not different from the control. On 2 October the Admire 2 F at 0.5 lb ai/ac treatment, Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt, and Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt followed by Provado 192 FL at 0.05 lb ai/ac all had significantly greater numbers of adults than the control. The Admire 2 F at 0.5 lb ai/ac treatment, Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt, Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt followed by Provado 192 FL at 0.05 lb ai/ac, and Gaucho 480 FS seed treatment at 1.51 lb ai/cwt all had significantly greater numbers of adults than the control on 9 October. All imidacloprid treated tomatoes had significantly fewer whitefly nymphs than the control on 26 October, there were no differences among the treatments on 2 October, and only the Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt and Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt followed by Provado 192 FL at 0.05 lb ai/ac treatments had significantly fewer nymphs than the control on 9 October. Gaucho 480 FS seed treatment at 1.51 lb ai/cwt and Gaucho 480 FS seed treatment at 3.49 lb ai/cwt treatments were significantly shorter than the control on 25 September, there were no differences among the treatments on 2 October, and only the Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt and Admire 2 F at 0.5 lb ai/ac followed by Gaucho 480 FS seed treatment at 4.99 lb ai/cwt followed by Provado 192 FL at 0.05 lb ai/ac treatments were significantly taller than the control on 9 October. Differences in plant height did not appear to be related to the imidacloprid treatment nor to whitefly infestation levels.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: March 1996 through June 1996.

Silverleaf Whitefly Control in Cantaloupe Melons, 1996

A stand of Cantaloupe melons, var. Topmark, was established at UC Desert Research & Extension Center 13 March 1996. Ten insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: Admire 2F at 0.25 lb ai/ac followed by Capture 2EC at 0.08 lb ai/ac+ Thiodan 3EC at 0.5 lb ai/ac, Capture 2EC at 0.08 lb ai/a+ Thiodan 3EC at 0.5 lb ai/a, Mycotrol WP at 1 lb product/ac, Mycotrol WP at 1 lb product/ac + Capture 2EC at 0.06 lb ai/ac, Mycotrol EC at 2 pt product/ac, Mycotrol EC at 2 pt product/ac+ Capture 2EC at 0.06 lb ai/ac, CGA-215944 50WP at 0.094 lb ai/ac+ Fenoxycarb 40WP at 0.063 lb ai/ac, CGA-215944 50WP at 0.094 lb ai/ac+ CGA-59205 35WP at 0.063 lb ai/ac, CGA-215944 50WP at 0.094 lb ai/ac+ CGA-59205 35WP at 0.094 lb ai/ac, and Danitol 2.4EC at 0.2 lb ai/ac + Vydate L at 0.5 lb ai/ac. Sylwet at 2.9 ml/2 gal and Buffer PS at 9.5 ml/2 gal were included in the Mycotrol spray mixtures; Sylgard at 2.4 ml/ 2 gal and Buffer PS at 9.5 ml/2 gal were included in all other spray mixtures. Admire 2F was injected 2 inches into seedlines 12 March 1996 at 1 pt/acre. Foliar insecticide treatments were applied four times at one week intervals starting 1 May 1996. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults on the fifth leaf from the terminal of the main stem cane from five plants at random in each plot via the leaf turn method on 13, 20 & 27 May 1996. Silverleaf whitefly nymphs were counted on two leaf disks of 1.25 cm^2 from five crown leaves extracted from randomly selected melon plants in each plot on 23 April and 6, 13, 20 & 27 May 1996. Yield data were recorded as number of marketable fruit from 0.002 acre per plot on 7 June 1996.

On the 20 May sampling date only Admire 2F followed by Capture 2EC + Thiodan 3EC, and Capture 2EC + Thiodan 3EC had significantly fewer whitefly adults than the untreated control, P=0.05. On 27 May, CGA-215944 50WP at 0.094 lb ai/ac+ CGA-59205 35WP at 0.094 lb ai/ac, Mycotrol EC + Capture 2EC, and Capture 2EC + Thiodan 3EC had significantly fewer whitefly adults than the untreated control. Only Mycotrol EC + Capture 2EC, Admire 2F followed by Capture 2EC + Thiodan 3EC, and Capture 2EC + Thiodan 3EC had significantly fewer whitefly adults than the untreated control for seasonal mean values. Whitefly nymph numbers were significantly lower for Mycotrol EC + Capture 2EC, Admire 2F followed by Capture 2EC + Thiodan 3EC, and Capture 2EC + Thiodan 3EC as compared to the untreated control on 27 May, 1996. Only Admire 2F followed by Capture 2EC + Thiodan 3EC, and Capture 2EC + Thiodan 3EC had significantly more marketable fruit than the untreated control.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: March 1996 through July 1996.

Silverleaf Whitefly Control in Tomato, 1996

A stand of processing tomatoes, var. Hunt 100, was established at UC Desert Research & Extension Center 13 March 1996. Eleven insecticide treatments and an untreated control were replicated 4 times in a randomized complete design. Insecticide treatments were as follows: Admire 2 F at 0.25 lb ai/ac followed by Baythroid 2 at 0.025 lb ai/ac, Admire 2 F at 0.25 lb ai/ac followed by Baythroid 2 at 0.044 lb ai/ac, Danitol 2.4 EC at 0.2 lb ai/ac+ Monitor 4 at 0.75 lb ai/ac, V-71639 0.83 EC at 0.044 lb ai/ac, V-71639 0.83 EC at 0.066 lb ai/ac, Provado 1.6 F at 0.05 lb ai/ac, BAS030011I 75 WP at 0.15 lb ai/ac, BAS030011I 75 WP at 0.3 lb ai/ac, Applaud 70 WP at 0.25 lb ai/ac, Applaud 70 WP at 0.25 lb ai/ac+ Phaser 3EC at 1 lb ai/ac, AC303,630 2 SC at 0.15 lb ai/ac. Sylgard 309 at 2.4 ml/ 2 gal and Helena Buffer PS at 9.5 ml/2 gal were included in all spray mixtures. Admire 2 F was injected 2 inches into seedlines 12 March 1996 at 1 pt/acre. Foliar insecticide treatments were applied 4 times at weekly intervals starting 2 May 1996. Silverleaf whitefly adults were sampled from 10 plants at random in each plot via a modified "Dustbuster" suction sampling method on 14, 21, 27 May , and 4 June 1996. Silverleaf whitefly nymphs were counted on 4 leaf disks of 1.25 cm^2 from five 5th position leaves down from the terminal extracted from plants selected at random in each plot on 1, 8, 15, 22, 28 May , and 4 June 1996. Yield data were recorded on 7 July 1996, as numbers of marketable fruit and pounds of marketable fruit per 0.002 acre for each plot. Percent irregular ripening was determined by slicing 10 mature fruit at harvest on 18 July 1996.

On 14 May only Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly adults than the untreated control, P=0.05. Applaud 70 WP + Phaser 3EC, both V-71639 0.83 EC treatments and Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly adults than the untreated control on 21 May. On 28 May only Danitol 2.4 EC + Monitor 4 and V-71639 0.83 EC at 0.044 lb ai/ac had significantly fewer whitefly adults than the untreated control. There were no differences among the insecticide treatments and the untreated control for numbers of whitefly adults on 4 June 1996. Admire 2F followed by Baythroid 2, Applaud 70 WP + Phaser 3EC, and Danitol 2.4 EC + Monitor 4 all had significantly fewer whitefly adults than the untreated control for seasonal totals. There were no differences among the insecticide treatments and the untreated control for numbers of nymphs on 1 & 8 May. On 15 May only Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly nymphs than the untreated control, P=0.05. Admire 2 F followed by Baythroid 2, both V-71639 0.83 EC treatments and Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly nymphs than the untreated control on 22 May 1996. Both V-71639 0.83 EC treatments and Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly nymphs than the untreated control on 29 May 1996. Applaud 70 WP + Phaser 3EC, Admire 2 F followed by Baythroid 2, V-71639 0.83EC at 0.066 lb ai/ac, and Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly nymphs than the untreated control on 4 June. Baythroid 2, both V- 71639 0.83 EC treatments and Danitol 2.4 EC + Monitor 4 had significantly fewer whitefly nymphs than the untreated control for seasonal totals. Only the V-71639 0.83EC at 0.066 lb ai/ac insecticide treatment had lower percent irregular ripening than the untreated control. There were no differences among the insecticide treatments and the untreated control for numbers of marketable fruit and pounds of marketable fruit.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: March 1996 through December 1996.

Silverleaf Whitefly Control in Cotton, 1996

A stand of cotton, var. DPL 5415, was established at UC Desert Research & Extension Center 20 March 1996. Nine insecticide treatments and an untreated control were replicated four times in a randomized complete design. Insecticide treatments were as follows: Capture 2EC at 0.08 lb ai/ac + Orthene 90S at 0.5 lb ai/ac, Capture 2EC at 0.08 lb ai/ac + Curacron 8EC at 0.5 lb ai/ac, Mustang 1.5EW at 0.045 lb ai/ac + Orthene 90S at 0.5 lb ai/ac alternating with Thiodan 3EC at 0.75 lb ai/ac + Ovasyn 1.5EC at 0.25 lb ai/ac, V-71639 0.83EC at 0.054 lb ai/ac applied at 2wk intervals, V-71639 0.83EC at 0.054 lb ai/ac applied at 3wk intervals, Danitol 2.4EC at 0.2 lb ai/ac + Orthene 90S at 0.5 lb ai/ac, CGA-215944 50WP at 0.094 lb ai/ac + Fenoxycarb 40WP at 0.063 lb ai/ac applied at 2wk intervals, CGA-215944 50WP at 0.094 lb ai/ac + CGA-59205 35WP at 0.063 lb ai/ac applied at 2wk intervals, and CGA-215944 50WP at 0.094 lb ai/ac + CGA-59205 35WP at 0.094 lb ai/ac applied at 2wk intervals. Helena Buffer PS at 23.6 ml/5 gal. and Sylgard 309 at 5.9 ml/5 gal. used with all insecticide spray treatments. Foliar insecticide treatments were applied eight times at weekly intervals starting 4 June 1996. Silverleaf whitefly adults were sampled from five plants at random in each plot via the leaf turn method fifth main stem leaf from the terminal on 3, 10, 20 & 25 June, and 1, 9, 16 & 30 July 1996. Silverleaf whitefly nymphs were counted on two leaf disks of 1.25 cm^2 from five 5th position leaves down from the terminal extracted from randomly selected plants in each plot on 3, 10, 20 & 25 June, and 1, 9, 16, 23 & 30 July 1996. Yield data were recorded on 28 August 1996. Seed cotton was hand picked from 0.002 acre per plot. Cotton samples were ginned and lint samples were sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

There were no differences for numbers of whitefly adults among the plots to receive insecticide treatments and the control on 3 Juneprior to insecticide treatments. Only Capture 2EC + Orthene 90S, Capture 2EC + Curacron 8EC, and Danitol 2.4EC + Orthene 90S treatments all had significantly fewer adult seasonal means than the untreated control, $P \leq 0.05$. Only CGA-215944 50WP at 0.094 lb ai/ac + Fenoxycarb 40WP at 0.063 lb ai/ac applied at 2wk intervals, CGA-215944 50WP at 0.094 lb ai/ac + CGA-59205 35WP at 0.063 lb ai/ac applied at 2wk intervals, and CGA-215944 50WP at 0.094 lb ai/ac + CGA-59205 35WP at 0.094 lb ai/ac applied at 2wk intervals had seasonal nymphal means that were not lower than the untreated control and seed cotton yields that were not greater than the control.

Investigator's Name(s): Eric T. Natwick.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: September 1995 through April 1996.

Effects of Silverleaf Whitefly Feeding on Sugar Beet Yield, Percent Sugar, and Leaf Petiole Chlorosis

A stand of sugar beet, Var. HH77, was established at the UC Desert Research & Extension Center by planting on 6 September 1995 and furrow irrigated 8 September 1995. Five insecticide treatments and an untreated control were included in a randomized complete block design with five replicates. The insecticide treatments (Admire 2 F at 0.5 lb ai/ac, Danitol 2.4 EC at 0.2 lb ai/ac, Monitor 4 at 0.5 lb ai/ac, Danitol 2.4 EC at 0.2 lb ai/ac tank mixed with Monitor 4 at 0.5 lb ai/ac, and Admire 2 F at 0.5 lb ai/ac followed by Danitol 2.4 EC at 0.2 lb ai/ac tank mixed with Monitor 4 at 0.5 lb ai/ac) were included to establish varying levels of silverleaf whitefly nymphs on the sugar beet plants among the treatments. Admire 2 F treatments were injected two inches below the seedlines on 6 September 1995 prior to planting. Foliar spray treatments were applied on 4 & 11 October 1995. The whitefly nymphs were sampled by extracting five leaves from plants at random in each plot on 26 September and 2, 10, 16, 24 & 30 October 1995. Leaf petioles were sampled for chlorosis by examining ten plants at random per plot on 16 & 24 October 1995. Sugar beets were harvested from ten row feet in each plot, counted, and weighed in pounds on 17 April 1996. Holly Sugar Corporation also counted and weighed the beets at the Brawley, CA factory, trimmed the crowns at a 60 degree angle around the circumference, removed the loose soil, and reweighed the beets. Holly Sugar Corporation also performed analysis for percentage of sugar and nitrate as ppm in the beet samples.

There were no differences among the treatments for whitefly nymphs from 26 September through 16 October ($P \leq 0.05$, ANOVA). On 24 October, the control had 4.8 nymphs per cm^2 which was significantly greater than all insecticide treatments except Admire 2 F at 0.5 lb ai/ac with 2.0 nymphs per cm^2. Admire 2 F at 0.5 lb ai/ac followed by Danitol 2.4 EC at 0.2 lb ai/ac tank mixed with Monitor 4 at 0.5 lb ai/ac had the fewest nymphs (0.2 per cm^2) on 24 October which was significantly lower than Admire 2 F at 0.5 lb ai/ac and Monitor 4 at 0.5 lb ai/ac which had 1.2 nymphs per cm^2. Danitol 2.4 EC at 0.2 lb ai/ac and Danitol 2.4 EC at 0.2 lb ai/ac tank mixed with Monitor 4 at 0.5 lb ai/ac each had 0.4 nymphs per cm^2 which was significantly less than the number of nymphs for Admire 2 F at 0.5 lb ai/ac. There were no differences among the treatments for nymphs on 30 October. On 16 October, Admire 2 F at 0.5 lb ai/ac followed by Danitol 2.4 EC at 0.2 lb ai/ac tank mixed with Monitor 4 at 0.5 lb ai/ac and Danitol 2.4 EC at 0.2 lb ai/ac had no petiole chlorosis while the percent chlorosis for other treatments including the untreated control ranged from 18 % to 26.27 %. The control (19.33 %) and the Monitor treatment (24.94%) had significantly greater percentages of petioles with chlorosis than the other treatments, which ranged from 0 - 7.37 %, on 24 October. There were on differences in sugar beet gross weight, net weight, percent sugar, or ppm nitrate among the treatments at harvest.

Investigator's Name(s): Nilima Prabhaker[1], N. C. Toscano[1], S. J. Castle[2], and T. J. Henneberry[3].

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Stability of Imidacloprid Resistance by Various Preventive Strategies in Silverleaf Whiteflies (Homoptera: Aleyrodidae)

One of the most encouraging developments in whitefly management in Imperial Valley, CA, has been the introduction of imidacloprid-formulated insecticides. The insecticide imidacloprid represents an unconventional class of insecticides with a novel mode of action. Imidacloprid provides season-long control in fall vegetables and spring melons requiring fewer treatments than with spray insecticides. As a new chemistry, this compound serves as an important alternative insecticide to the pyrethroids, organophosphates, and cyclodienes that have been heavily used for controlling whiteflies. Imidacloprid's greatest activity against whiteflies is through systemic uptake by plants. The system action of imidacloprid results in long term persistence and also generates higher selection for resistance by its more uniform occurrence in all parts of a plant compared to spray insecticides. Therefore, resistant management programs are essential for prolonging the life of imidacloprid under field conditions.

Towards this goal we are evaluating the effect of restriction of imidacloprid treatments, alternation of imidacloprid with insecticides having different modes of action to delay resistance and the effect of immigration of susceptible individuals.

A resistant strain of *Bemisia tabaci* was established by selection with imidacloprid for approximately two years with a resistance level of 77-fold. The stability of imidacloprid resistance in this strain is under evaluation using a rotation regimen of different chemistries and also withdrawing selection with imidacloprid. Three subsets of this resistant colony were subjected to selection by an alternation regimen with bifenthrin, endosulfan, imidacloprid, methomyl, and chlorpyrifos; or no selection with imidacloprid or alternation with imidacloprid-bifenthrin sequentially. Susceptibility to imidacloprid was monitored using a hydroponic bioassay developed in this laboratory. Resistance to imidacloprid remained high with continuous imidacloprid selection (83-fold). Lower levels of resistance to imidacloprid were observed in whiteflies subjected to a rotation regimen with different insecticides (resistance ratio [RR] 5-fold). Decline in resistance to imidacloprid was slow initially in the absence of selection but decreased considerably after a few generations (seven) to 2-fold. Our study indicates that resistance to imidacloprid declines when treatments are withdrawn. Under the alternation regimen of imidacloprid-bifenthrin selection, resistance declined but not completely, suggesting the presence of cross resistance to bifenthrin in this strain.

Investigator's Name(s): D. J. Schuster.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1995-96.

Toxicity of Biorational Pesticides the Lacewing Species *Ceraeochrysa cubana*

Azadirachtin (Align™), mineral oil (Sunspray Ultrafine Oil™), soap (M-Pede™) and a pyrethroid standard, bifenthrin (Brigade™) were evaluated at 0, 1X, 2X and 3X the recommended field rates for toxicity to eggs, larvae and adults of the lacewing *Ceraeochrysa cubana* in the laboratory. Eggs were dipped in pesticidal preparations and held in small petri dishes for hatching. The topical toxicity to adults and larvae were evaluated by chilling the insects and misting them with insecticidal preparations in petri dishes. After drying, adults were placed together with food in screened, one pint cartons ringed with banner paper. Mortality and oviposition were observed 72 hours later. Larvae were placed individually in small petri dishes, fed after 48 hours and observed for mortality after 72 hours. To determine the residual toxicity to adults, pesticidal preparations were misted onto the insides of 4 ozs plastic specimen cups. After drying, one pair was placed in each cup with food. The cups were sealed with a ventilated lids and mortality was observed after 72 hours. The residual toxicity to larvae was evaluated by misting pesticidal preparations on a glass plate. After drying, the plate was covered with a plexiglass sheet with holes. A slitted PVC ring coated on the inside with teflon was fitted into each hole in the plexiglass, thus forming an exposure chamber with the pesticidal residue on the bottom. Larvae were placed individually into the chambers which were sealed with organdy cloth held in place with a rubber bands. The larvae were fed every 48 hours until pupation or death occurred.

Bifenthrin was toxic topically and residually to adults but was not toxic to eggs or larvae. At field concentrations, azadirachtin, oil and soap generally were not toxic to larvae and adults either topically or residually. Oil was toxic to eggs but azadirachtin and soap were not. Soap, neem and oil appear to be potential biorational pesticides for managing the silverleaf whitefly and other lacewing prey.

Investigator's Name(s): Alvin M. Simmons and D. Michael Jackson.

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Ultrasonic Fogging Device for Managing Whiteflies

A study was set up to evaluate the feasibility of using an ultrasonic fogging device for managing whiteflies with low dosages of contact insecticides. The research was conducted in cooperation with Strauch and Sons, Inc., Bethesda, MD. Tests were conducted on *Bemisia argentifolii*. Insecticide treatments with conventional applicators generally do not reach the bottom leaf surface where the whitefly feeds. The initial work was done to determine if this fogging device could provide good under-leaf coverage and good whitefly management at low dosages. Tests were conducted on collard in two plastic-covered greenhouses, both 6.1 meters by 4.6 meters. One greenhouse was used for the fog treatments and the other was used for the untreated checks. The plants were grown in a separate greenhouse before the treatments.

Residue analysis indicated that a high percentage (76%) of a biorational sugar ester insecticide was delivered to the bottom leaf surface compared with the upper surface. The fogger provided good control of whiteflies on test plants while using reduced rates of a foliar imidacloprid compared with the labeled rate. Rates as low as 1/16 of the labeled rate provided high adult mortality. Moreover, the fogger provided high whitefly mortality under vapor pressure deficits ranging from low (2.7 mb) to high (57.8 mb). A wettable powder did not work in the fogger because it clogged the machine, which lacked agitation. Overall, the fogging device looks very promising for managing whiteflies in a greenhouse system and has a possibility for adaptation for field use.

Investigator's Name(s): Nick C. Toscano[1], N. Prabhaker[2], S. J. Castle[2], T. J. Henneberry[2], G. Ballmer1, E. Natwick[3], and R. Kallenbach[4].

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Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996-97

Areawide Resistance Monitoring of Sweetpotato and Silverleaf Whiteflies, *Bemisia tabaci* and *B. argentifolii* (Homoptera: Aleyrodidae) in California

Control of the sweetpotato and silverleaf whitefly in California is dependent upon year-round insecticide use. The overlapping of crops which host whiteflies throughout the annual cropping cycle encourages high whitefly densities. As a result of this and the use of insecticides, there is a potentially high selection pressure for resistance development in *Bemisia* spp. Because insecticides played an important role in crop protection strategies against these whitefly pests, an insecticide management program was instituted.

A resistance monitoring technique using yellow sticky cards sprayed with insecticides efficiently and sensitively detected resistance in whitefly field populations. The distribution of resistance in the sweetpotato and silverleaf whitefly, *B. tabaci* and *B. argentifolii,* in California was determined with this technique. Thirty-two *B. tabaci* (Gennadius) populations exhibited various levels of resistance to sulprofos (Resistance Ratio [RR] ranging from 19 to 104) and cypermethrin (RR ranging from 14 to 82) during 1987 and 1988, indicating that insecticide resistance is widespread in the Imperial Valley, CA.

In 1993-1994, the insecticide-coated yellow sticky card technique was used for monitoring resistance in *B. argentifolii* populations in Imperial, Palo Verde, and San Joaquin Valleys, California. Considerable differences in RR for bifenthrin, endosulfan, chlorprifos, and methomyl treatments were observed among whitefly populations from the three geographic regions. Bioassays indicated in 1993-1994 that methomyl was effective against adults in all locations.

In 1994, a grower supported resistance monitoring program was initiated using the yellow sticky card technique sprayed with grower available insecticides. This program provides baseline data for a number of insecticides used for control of *B. argentifolii* in California. Continuous monitoring of the whitefly populations for changes in resistance frequencies in large regions allowed decisions regarding effective whitefly management strategies to be formed. Whitefly insecticide resistance monitoring data and management strategies were communicated to farmers and pest control advisors via Farm advisors, newsletters, newspapers, and Internet.

Investigator's Name(s): Y. Yasui[1], P. Ellsworth[2], J. Lublinkhof[3] and D. Comer[4].

Affiliation & Location: [1]Nihon Nohyaku Co., Ltd., Osaka, Japan; [2]University of Arizona, Maricopa Agricultural Center, Maricopa, AZ; [3]Department of Entomology, Tucson, AZ; and [4]AgrEvo USA Co., Wilmington, DE.

Research & Implementation Area: Section C: Chemical Control, Biorationals, and Pesticide Application Technology.

Dates Covered by the Report: 1996.

Monitoring *Bemisia argentifolii* Susceptibility to Buprofezin

Susceptibility of field populations of *Bemisia argentifolii* to buprofezin (Applaud®) was monitored in laboratory bioassays developed by Yasui in 1993. This monitoring technique is simplified for field use and is accessible to anyone with very simple tools, a dissecting scope, and reasonable control over near "room" temperature conditions. Animals from the field are assayed directly; the F1 generation is not assayed as is usually the case. Briefly, the 2nd leaf below the terminal of a cotton plant is collected intact from the field. Leaf blades are then trimmed and held in vials of water for about 7 days at which time both sides of the leaves are sprayed to saturation with Applaud 70WP. Leaves are held for a further 12 days and nymphs are classified as dead or alive. LC50 and LC95 statistics are determined from probit analyses.

Whiteflies from the cotton fields of two grower-cooperators in central Arizona and from replicated small plots at the Maricopa Agricultural Center were assayed. Grower fields received one application of Applaud, the maximum allowed under the emergency registration (Section 18). No shift in susceptibility to buprofezin was observed either within this year or when compared to baseline data taken from Arizona populations 3 years ago. Furthermore, in small plot studies in which plots received up to 4 sprays of Applaud, no shifts in susceptibility to buprofezin were observed. Overall, LC50 values ranged from ca. 3-12ppm. These data serve as a baseline for future susceptibility monitoring and indicate minimal risk of resistance under currently regulated use patterns.

TABLE C. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section C: Chemical Control, Biorationals, and Pesticide Application Technology

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
C.1 & C.2 New chemistry: Identify new chemicals and biopesticides for registration that selectively control SLWF withminimal effects on beneficial organisms.	Year 5: Formulate control strategy based on research progress that indicates rates, gal/acre, frequency of application, and associated secondary pests. Implement alternating sequence management systems to prevent resistance.	X		Growers in all the infested regions have progressed significantly in their ability to manage whiteflies, in part due to correct use of insecticides and biorationals. Incorporation of only on application of the IGRs pyriproxyfen and buprofezin into the whitefly management system for cotton in Arizona and California resulted in less damage and reduced tolerance to pyrethroids.
C.3 Economic thresholds: Relate schedules and methods of application to economic thresholds.	Year 5: Develop protocols for SLWF economic thresholds and insecticide use on as-needed basis.	X		Thresholds developed for cotton and melons in the west and southwest were widely utilized by growers and consultants.
C.4 & C.5 Insecticide resistance: Elucidate mechanisms, monitor whitefly populations and develop management systems.	Year 5: Initiate studies to develop insecticide resistance management and outline areawide pesticide rotation systems.	X		The second year of resistance management trials in Arizona and California showed that the trend toward increasing pyrethroid resistance Maricopa county was arrested, thanks in part to the inclusion of IGRs in the rotational system.
C.6 Application technology: Develop improved methods for application or delivery of materials to enhance control and conserve natural enemies.	Year 5: Determine need for continued research.	X		It was determined that the need still exists to improve underleaf coverage to assure the role of contact biopesticides and biorationals.
C.7 Integration with other control tactics: Integrate chemical control with biological and cultural control.	Year 5: Develop standard protocols for chemical control and natural enemy integrated systems for best control in relation to economic thresholds.	X		Sugar esters and insecticidal soaps and certain IGRs were shown to be safe to *Encarsia* species. Sugar esters and mineral oils were shown to be safe to at least the coccinellid predator *Nephaspis oculatus*. The IGR fenoxycarb and *N. oculatus* were combined to control whiteflies in a preliminary test on hibiscus.

Investigator's Name(s): Carlos E. Bográn, Kevin M. Heinz, Matthew Ciomperlik and Lloyd Wendel.

Affiliation & Location: Texas A&M University, Department of Entomology, College Station TX.

Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: May-December 1996.

Intespecific Interactions Among *Bemisia argentifolii* Parasitoids

Biological control has been a major focus of the National Research and Action Plan for the Management of the silverleaf whitefly, *Bemisia argentifolii*. Even though results from laboratory and greenhouse studies are promising, the desired levels of control have not been achieved in field crops. To improve whitefly suppression after releases of natural enemies into field crops, an understanding of the potential effects of interspecific interactions is essential. Our study takes an experimental approach to the study of interspecific interactions, their role in structuring parasitoid communities, and their impact on host population dynamics. Changes in the population densities of two or more interacting species over time should reveal the strength of competition. Furthermore, factors such as resource availability and resource utilization patterns of competing animals may mediate interaction intensity. The specific objectives of our study were to: 1) evaluate the occurrence and dynamics of interspecific interactions among three parasitoid species of the silverleaf whitefly, 2) assess changes in the occurrence of these interspecific interactions in response to (initial) host densities, and 3) assess the impact of interspecific interactions on the biological control of the silverleaf whitefly in field cages. Three species of parasitoids, *Eretmocerus mundus* (M92014, Murcia, Spain), *Encarsia formosa* (M92030, Beltsville, MD) and *Encarsia pergandiella* (native, TX) were selected based upon their performance in pre-release evaluations and because they represent the diversity of reproductive strategies found in Aphelinid parasitoids of the silverleaf whitefly. A field cage study was set up using Deltapine-50 cotton on experimental plots at Mission, TX (USDA/APHIS/PPQ Biological Control Laboratories). The experimental units were forty eight cages (3.3 x 3.3 x 1.7m), covered with 52 mesh Lumite™ fabric that were placed over three, 10-ft long contiguous rows of cotton. The eight treatments represented the releases of: 1) no parasitoids, 2) *Er. mundus* alone, 3) *E. formosa* alone, 4) *E. pergandiella* alone, 5) *Er. mundus* and *E. formosa*, 6) *Er. mundus* and *E. pergandiella*, 7) *E. formosa* and *E. pergandiella*, and 8) *Er. mundus* and *E. formosa* and *E. pergandiella*. Treatments were assigned to each of two initial host densities: inoculations of 1 whitefly per plant per week for three consecutive weeks (low initial density) and inoculations of 3 whiteflies per plant per week for three consecutive weeks (high initial density). Each treatment and starting condition was replicated three times (8 parasitoid treatments x 2 starting conditions x 3 replicates = 48 cages). Whitefly releases were initiated when plants had between 2 and 3 nodes (mainstem leaves). Parasitoid releases were done weekly for two weeks and started the week of the last whitefly release. Sampling was done each week and for a period of nine weeks after the last parasitoid release (a pre-release sample was taken before parasitoid releases for comparison). On each date a sub-sample was taken of all the mainstem leaves from three plants arbitrarily selected from each cage. Wheteflies on each leaf were censused by lifestage together with the number of parasitoid pupae of each parasitoid species. No significant differences were found in the pupal densities of each parasitoid species whether in the presence or absence of competitors. Initial whitefly density affected pupal densities *Er. mundus* but not *E. formosa* and *E. pergandiella* (7,508 ± 2,728 and 858 ± 233 *Er. mundus* pupa per cage (mean ± 1 SE) for the high and low initial densities, respectively). Silverleaf whitefly densities were significantly different ($p<0.05$) between the control (154,168 ± 30,566 nymphs per cage) and the parasitoid releases (21,518 ± 326 nymphs per cage). No difference, however, was found in the nymphal densities of silverleaf whitefly between the release of one, two or three parasitoid species. The lack of treatment effects on the densities of parasitoids suggest an absence of interspecific interactions within a cotton production cycle. The fact that all parasitoid releases suppressed whitefly populations suggests no deleterious effects of interspecific interactions on biological control under our experimental conditions.

Investigator's Name(s): Albino Chavarria, John A. Goolsby, and Lloyd E. Wendel.

Affiliations & Locations: USDA-APHIS-PPQ, Mission Biological Control Center.

Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1995.

Field Cage Rearing of Exotic Parasitoids

Field cage insectary production of SPWF and its natural enemies is a reliable, year-round method of mass rearing individuals for field release programs. The advantages of field cage production are: 1) lower cost of production; 2) higher production; and 3) a more robust field reared parasitoid. Selected species of parasitoids are produced in (10 x 10 ft.) field cages containing 154 pots of eggplant. Each cage is infested with 100,000 SPWF adults which are held 4 days for oviposition. When the SPWF nymphs reach 2nd instar up to 10,000 adult parasitoids are released over a 3-day period. The mature parasite pupae are harvested by clipping the leaves which are held for emergence of adults.

Current methods of field insectary production reliaably produced 70,000 adult parasitods per cage with a new cage ready for harvest each week. Production for three *Eretmocerus* spp. (M92014 Spain) and (M95012 Pakistan) and (M95104 United Arab Emirates) were compared for the months of Jan. through Nov. 1996. The mean fecundity per female was not significantly different at 10.4, 10.8 and 12.8 for M92014, M95012, and M95104 respectively. This represents a 30.7 percent increase in production as compared to 1995. Over 4 million parasitoids were reared during 1996 using these methods.

Investigator's Name(s): Matthew Ciomperlik[1], John Goolsby[1], Tad Poprawski[2], Lloyd Wendel[1], and Steve Wraight[2].

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the Report: Fall 1995 - Fall 1996.

Demonstration of Biological Control Based IPM of Sweetpotato Whitefly

The BC-IPM Demonstration project is an attempt to evaluate the compatibility of current biological and chemical control methods to manage Sweetpotato whitefly (SPWF) populations below economically damaging levels. The biologically based IPM approach combines the use of parasitoids, predators, pathogens and, where needed, biorational or environmentally safe insecticides to control SPWF populations. So far the biological control based IPM approach has been used in a year round rotation of broccoli, fall cucumbers, cantaloupe melons, and cotton at a 20 acre irrigated farm located at USDA-APHIS-PPQ-Mission Biological Control Center on Moore Airbase, Mission, TX. The BC-IPM approach was used in the fall of 1995 to produce 3 acres of cucumbers, 3 acres of broccoli in the winter of 1995, 8 acres of cantaloupe melons in the spring of 1996, 5 acres of cotton in the summer of 1996, and 8 acres of pickling cucumbers in the fall of 1996.

Cucumbers, Fall 1995. The BC-IPM project to show that fall cucumbers could be grown in the LRGV using BC-IPM methods was a fundamental success. Analysis of the data indicate that *Beauveria bassiana* (Mycotrol) spray applications reduced populations of whitefly nymphs by 60-70% within three to four weeks after initiation of the spray program; numbers of late instar nymphs were reduced by 70-75%. Rates of parasitism varied considerably between treatments, reaching levels as high as 25 to 30% in some plots late in the growing season. In addition, data from Admire + parasitoid plots suggest that Admire (imidacloprid) and parasitoids may be synergistic in that parasitoids are able to utilize whitefly nymphs that escape mortality due to the systemic insecticide.

Broccoli, Winter 1995. Whitefly populations are generally low in winter crucifer crops in the LRGV of Texas. As such, crops like broccoli, cauliflower, and cabbage are not chemically treated for whitefly control. Therefore, our winter trials on broccoli were aimed at determining whether augmented exotic parasitoids would colonize and suppress whitefly numbers until harvest. Although whitefly nymph densities were less than one nymph per cm^2, moderate rates of parasitism by exotic *Eretmocerus* (M92014) were observed. The overall benefits of releasing exotic parasitoids into winter crucifers are reductions in whitefly densities that eventually disperse to spring crops, and building a reservoir of parasitoids that will be synchronized with whitefly for emergence in the spring.

Cantaloupe Melons, Spring 1996. A single application of Admire and 3 weekly parasitoid releases totaling 23 K per acre were sufficient to control whitefly throughout the cantaloupe crop. The degree of control was so effective that mid- to late season remedial applications of Mycotrol WP (*Beauveria bassiana*) were not warranted. Parasitism by released exotic *Eretmocerus* (M95012 Pakistan & M92014 Spain) was substantial, reaching levels of approximately 90% by mid-season, even though whitefly densities were less than 0.25 nymphs per cm^2. This data suggests that the exotic parasitoids show a high degree of host searching, and provides further evidence that parasitoids are compatible with the use of imidacloprid.

Cotton, Spring/Summer 1996. Whitefly densities were low throughout much of the cotton crop, never exceeding one nymph per cm^2. The absence of a late season peak in whitefly numbers suggest that the host population was being kept in check by parasitism and by predation. Parasitism rates by exotic *Eretmocerus* and native *Encarsia pergandiella* reached levels of 23% and 12% late in the season respectively. In addition, a large proportion of whitefly nymphs showed signs of predation and mortality due to unknown causes.

To determine the success or shortcomings of the biologically based - IPM program, the economics and marketability of each crop was evaluated.

Investigator's Name(s): Allen C. Cohen, Lisa Smith and Donald Brummett.

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Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: March 1996 through December 1996.

Development of an Artificial Diet for *Chrysoperla carnea*

We developed a semi-solid artificial diet for the green lacewing *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae). The diet has thus far supported 13 continuous generations of lacewings which have weights, fecundities and fertilities comparable to those of lacewings grown on the factitious host, *Ephestia* and are superior to another widely used host, *Sitotroga*. Development times for diet-reared lacewings are slightly longer (9.5 days for larvae) than those reared on *Ephestia* (8.1 days). The lacewings are being produced in cells covered with organdy cloth, and larvae feed readily through the cloth with a Parafilm packet of the diet whose texture is that of a stringy paste. Larvae from every generation were tested for their ability to resume predation on natural hosts, and all generations voraciously consumed whitefly nymphs at rates of up to several hundred smaller instars per day. The diet costs about 6-7 dollars per kg compared to about 600 per kg for factitious host eggs.

Investigator's Name(s): Allen C. Cohen, Lisa Smith and Donald Brummett.

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Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: March 1996 through December 1996.

Measurement of Nutrient Rewards for Predators Consuming Whiteflies: Sterols from *Bemisia argentifolii*

Predatory arthropods are generally thought to meet their sterol requirements from their prey's cholesterol content. We tested the sterol content of some predators (*Chrysoperla carnea, Geocoris punctipes and Serangium parcesetosum*) and whiteflies *B. argentifolii* to determine the relationship between predators and prey with respect to sterols that are a crucial part of an arthropod predator's nutrient reward. We found that the whiteflies are composed mainly of plant sterols (ß-sitosterol, stigmasterol and campesterol, as well as an unknown substance that elutes with the sterol fraction in TLC and GLC separations). Only about 13% of the whitefly's sterol composition is cholesterol. This means that predators of whiteflies must be able to deal with plant sterols, or they cannot use whiteflies as a prey.

Investigator's Name(s): T. J. Dennehy, L. Williams III, Xiaohua Li, M. Wigert, and E. Birdwell.

Affiliation & Location: Extension Arthropod Resistance Management Laboratory, Department of Entomology, University of Arizona, Tucson, Arizona.

Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1994 - 1996.

Whitefly Resistance in Insecticides in Arizona Cotton

We documented a resistance crisis in Arizona cotton from 1994 to 1995. By the end of the 995 season pyrethroid insecticides, synergized by organophosphates or carbamates, failed to control whitefly (*Bemisia argentifolii*) populations throughout much of Central Arizona. This resulted in a classic resistance treadmill, the end product of which was growers applying in excess of 8 to 12 whitefly treatments, and cotton being discounted by buyers due to honeydew contamination (stickiness), in some cases despite insecticide expenditures of $200-$300 per acre. We describe a multi-agency response to this resistance crisis. The strategy included two pivotal changes in whitefly management in Arizona: emergency registration for once-per-season use of the insect growth regulators, Knack® (pyriproxyfen) and Applaud® (buprofezin) and delayed use of pyrethroid insecticides. These new measures were incorporated into a three-stage chemical use strategy and were coupled with renewed emphasis on whitefly monitoring and thresholds and long-standing agronomic and cultural control recommendations.

The rapid response to the Arizona whitefly resistance crisis was facilitated by cooperation offered by scientists from England (Rothamsted Experimental Station) and Israel (Gilat Regional Experiment Station) and close working relations of government and university personnel with Arizona cotton growers and Cotton Incorporated. Since 1994, the Southwest Whitefly Resistance Working Group has met twice per year to reach consensus on recommendations for management of whitefly resistance in desert cotton. Additionally, a central role in documenting the buildup of resistance and the impact of the new resistance management strategy has been served by a first-of-its-kind Extension facility, the Extension Arthropod Resistance Management Laboratory (EARML). Results of the use of the 1996 whitefly resistance management program were very promising. Excellent whitefly control was observed throughout the State. Statewide monitoring results showed that levels of resistance to pyrethroid insecticides declined, relative to 1995, as did levels of lygus bug resistance to key insecticides. In areas of Central Arizona where resistance to pyrethroids required growers to apply 8-12 insecticide treatments in 1995, from 1-4 insecticide treatments were required in 1996.

Investigator's Name(s): Dan Gerling, Vasily Kravchenko, and Moshe Guershon.

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Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: January 1995 - January 1996.

Deraeocoris pallens Reuter, *Orius niger* Wolf and *Campilomma unicolor* Poppius. (Heteroptera) as predators of *Bemisia* nymphs

Field and laboratory observation were carried out on the behavior of three species to determine their possible utility as predators of *Bemisia*. The questions asked in this study were whether these species eat *B. tabaci*, and to what extent they also feed on plant leaves.

Field collected bugs (last instar nymphs and adults) were placed in Petri dishes in a 3-choice experiment. The 3-choices were: - 10 aphids (*Aphis gossypii* Glover), *B. tabaci* eggs and nymphs and leaves without prey. For each species we used 15 dishes (replicates), 3 specimens per dish. Preference of predators and predation of the whiteflies were estimated by recording every 30 minutes the number of insects feeding on each kind of food and by registering the number of eggs and nymphs of the whitefly left on the leaf. The observations lasted 6 hours (18 observations per dish). Thereafter, the food items were replaced with new ones. We also used a four-choice experiment to test if the bugs were strictly carnivorous. The insects were given 1 cm^2 pieces of a mature cotton leaf, 1 piece of a young leaf, filter paper with eggs of *Anagasta kuhniella* Zeller (Lepidoptera), and filter paper with no food. Daily consumption of whitefly nymphs was estimated by placing a leaf segment bearing precounted, 100 - 150 whitefly nymphs in a Petri dish (15 dishes per species). One bug was added and kept for 24 hours, after which the number of sucked nymphs was counted.

In order to find out if the presence of predators is correlated with the density of whitefly nymphs, we used two methods: a) on untreated cotton we examined weekly, from July till September, 10 top leaves of 60 - 80 plants and counted the number of leaves with whitefly nymphs, with predators and both nymphs and predators. b) in September we recorded the number of predators every 2 hours on 300 marked and labeled cotton leaves. The leaves were chosen randomly at the plant level of maximal infestation of *B. tabaci*. After 4 observation days, the leaves were collected in order to estimate the whitefly nymphs density and age.

Results and Discussion

In the **four-choice experiment** *D. pallens* and *C. unicolor* avoided the paper, and gathered on the leaf pieces. Nymphs of *D. pallens* showed clear preference for young leaves. They also fed often on the leaf tissue. *0. niger* did not show any significant preference as to presence on paper or leaves.

In the **three-choice experiments**, *C. unicolor* tended to suck the leaf more often than on the prey provided. When preying, they preferred eggs and nymphs of whitefly over aphids. The two other species preferred to feed on prey. *D. pallens* fed on the whitefly nymphs and aphids with equal preference, *0. niger* preferred eggs and young whitefly nymphs over aphids. Average consumption of whitefly nymphs per bug per 24 hours was: *C. unicolor* - 8.86, *D. pallens* - 26.52, *0. niger* -11.16.

Chi-square tests conducted with the **field observations** showed that, during the weekly counts, none of the bugs visited *B. tabaci*-infested leaves significantly more than clean leaves. Data from the 300 labeled leaves showed (significant at $P < 0.01$): that *D. pallens* nymphs were more abundant on leaves with high density of older whitefly nymphs, and *0. niger* adults were more common on leaves with eggs and very young nymphs of whitefly.

Investigator's Name(s): John A. Goolsby & Lloyd E. Wendel.

Affiliations & Locations: USDA-APHIS-PPQ, Mission Biological Control Center.

Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Colonization of Exotic Parasitoids in the Lower Rio Grande Valley and Wintergarden of Texas

Three species of exotic *Eretmocerus* parasitoids have proven to be most effective in a variety of crop plants and weed hosts based on laboratory and field evaluations conducted by Goolsby & Ciomperlik during 1993-96. The three species are *Eretmocerus* spp. (M92014-Spain), (M95012 - Pakistan), and (M95104 - United Arab Emirates). These species are being mass reared in for colonizaton in the Lower Rio Grande Valley of Texas, the Texas Wintergarden, and the San Joaquin Valley of California.

Parasitoids are mass reared in field insectary cages and shipped as adults in large petri-dishes provisioned with honey. A series of bi-weekly inoculative releases are made in each selected location. Agricultural locations are selected which have moderate densities of SPWF and where the effect of broad spectrum insecticides can be minimized. Samples are returned to MBCC to determine if successful colonization has taken place.

In the Texas Wintergarden, 41,000 (M92014), 99,000 (M95012), and 17,600 (M95104) were colonized in 17 locations over a 4 county area. Exotics parasitoids were recovered for the first time from sesame. In the LRGV, 160,500 (M92014), 255,000 (M95012), and 37,000 (M95104) were colonized in 40 locations in 3 counties and adjoining areas of northern Tamaulipas. Exotic *Eretmocerus* sp. were recovered from 53% of the release locations. We will continue to monitor the establishment and impact of the exotic parasitiods during 1997.

Investigator's Name(s): John A. Goolsby[1], Benjamin C. Legaspi, Jr.[2], and Walker Jones[3].

Affiliations & Locations: [1]USDA-APHIS-PPQ, Mission Biological Control Center; Joint affiliation: [2]USDA-ARS and Texas Agricultural Experiment Station, Weslaco, TX; and [3]USDA-ARS-BCPRU, Weslaco, TX.

Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Quarantine Screening of Natural Enemies

The purpose of quarantine screening is to determine which species of exotic parasitoids show the greatest potential for suppression of SPWF on selected crops. Tests were devised to measure fecundity per female on SPWF infesting specific crop plants. Results of these tests were used to prioritize which exotic species received emphasis in further field evaluation. Screein on Melons, *Cucumis melon*; cotton, *Gossypium hirsutus* and broccoli, *Brassica oleracea* was reported in 1995. The results of testing on *Sonchus olereae* (Sowthistle) and tomato are reported here.

Parasitoids were reared on hibiscus at the USDA-APHIS Mission Biological Control Center (MBCC). Plants were grown in the MBCC quarantine greenhouse facility which was maintained at temperatures and photoperiod similiar to field conditions for each crop. Plants were infested with adult *B. tabaci* and held 2 days for oviposition. Individual leaves with moderate egg densities were selected. All adult whitefly were removed from the leaves and then covered with an organza sleeve. Whitefly were held for 14 days until the nymphs reached 2nd and 3rd instars. Two parasite females from each of the cultures were released per leaf sleeve with 20 replicates (leaves) per species. Parasitoids were allowed to forage for 2 days and then removed. Leaves were removed from the plant 16 days after introduction of the parasitoids and examined for evidence of parasitism. The numbers parasitized and the percentage parasitism was determined for each of the species tested.

The results of the tomato test indicates that, of the 5 parasitoid species tested, there were significant differences in fecundity. Three *Eretmocerus* spp. from Taiwan, Pakistan, and Spain performed significantly better than the native *Eretmocerus* from Texas and *Eretmocerus furuhashii*. Although one of the *Eretmocerus* sp. (M95097) from Taiwan had a higher mean attack rate than the species from Pakistan and Spain, there was no significant difference between them.

The results of the *Sonchus olereae* (sowthistle) test indicates that, of the parasitoid species tested, there are significant differences in fecundity. Of the eight species tested, *Encarsia* sp. nr. *pergandiella* (M94055 - Brazil) attacked significantly more SPWF followed by *Eretmocerus* sp. nr. *mundus* (M92014-Spain). Both of these species have performed well in earlier screenings on melons, cotton, and cole crops. The effect of the wild host plant does not appear to significantly alter the fecundity of the exotic parasitoids tested. Key exotic parasitoids such as, (M92104 - Spain & M94055 - Brazil) could potentially move from field crops such as cotton and fall cucurbits into overwintering refuges of *Sonchus* and maintain their populations.

Investigator's Name(s): John A. Goolsby & Lloyd E. Wendel.

Affiliations & Locations: USDA-APHIS-PPQ, Mission Biological Control Center.

Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Importation of Exotic Natural Enemies for *Bemisia tabaci* (Biotype "B")

Six species/populations of *Eretmocerus* and *Encarsia* spp., were established in culture from collections made in Ethiopia, Malaysia, Northern Pakistan, and Sicily, during 1996. The foreign exploration was conducted by: A. Kirk (USDA-ARS-EBCL), and G. Terefe & D. Gerling (Univ. of Tel Aviv, Israel).

Natural enemies imported into the MBCC quarantine follow a set protocol which maximizes the number of unique species or biotypes cultured. Natural enemies from collectors are isolated into separate emergence containers by date, geographic location, and host plant. Individuals from each of the different genera or species are isolated from *Bemisia* immatures for analysis. Parasitoid adults from each potential culture are collected for characterization by both molecular geneticists and taxonomists. Individuals from each isolation can be characterized by DNA patterns within days after importation using RAPD-PCR while taxonomic identifications are in progress. The DNA patterns allow us to identify genetically unique populations of natural enemies and avoid duplicate cultures of similar organisms.

The parasitoids imported from Pakistan and Sicily were found to be duplicate geographic types to previous collections made in Pakistan and the Mediterranean. Both collections were combined with existing colonies to increase genetic diversity. A species of *Encarsia* in the cubensis group was imported from Ethiopia along with an *Eretmocerus* sp. which appears to have similar DNA banding pattern to a collection made in 1995 in the United Arab Emirates.

Exploration for natural enemies of SPWF has been conducted in the Mediterranean Region, South Central and Southeast Asia, and South America, the Arabian Peninsula and parts of Africa. Future exploration efforts for additional natural enemies of *Bemisia* by USDA will likely be limited.

Investigator's Name(s): John A. Goolsby[1] & Matthew A. Ciomperlik[1].

Affiliations & Locations: USDA-APHIS-PPQ, Mission Biological Control Center[1].

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: 1996.

Novel Method for Field Delivery of Parasitoids in Row Crops

Greenhouse grown seedling transplants inoculated with parasitoids "banker plants" provide a novel opportunity for field release of natural enemies in annual row crops. A portion of the seedlings can be inoculated with SPWF and selected parasitoids prior to transplanting. This methodology allows for more efficient early season release of known numbers of parasitoids in precise synchrony with the crop. In spring crops, such as cantaloupe melons, early-season releases of parasitoids have been shown to have the greatest impact on SPWF (Simmons & Hoelmer 1995; Ciomperlik & Goolsby 1996). Banker plant technology can be integrated with imidacloprid - Admirer and biorational materials such as *Beauveria bassiana* for season long control of SPWF thus avoiding late season applications of broad-spectrum insecticides. Elimination of late season insecticides in melons greatly increases the numbers of parasitoids available to migrate into cotton. The greatest benefits of this strategy may be realized when it is applied on a region-wide scale. Currently in the LRGV, 8000 acres of spring cucurbits are transplanted and the acreage is increasing each year. The potential to integrate this BC-IPM augmentation technique with current farming practices is great.

Greenhouse tests have been conducted with cantaloupe transplants which determined the optimum whitefly and parasitoid density per transplant, optimum cantaloupe variety, and toxicity of immature parasitoids on the transplant to imidacloprid. *Eretmocerus* sp. (M95012 - Pakistan) was selected based on its performance in the BC-IPM demonstration. Field testing of the banker plant technology is planned for spring 1997.

Investigator's Name(s): David Headrick, Tom Bellows, Tom Perring, and Bobbie Orr.

Affiliation & Location: Department of Entomology, University of California, Riverside.

Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: September 1995 - September 1996.

Natural Enemy Releases Against the Silverleaf Whitefly in the Imperial Valley

Agriculture in the southern desert valleys of Imperial County has been altered substantially by the introduction of the silverleaf whitefly. Since its discovery in California in 1990, the silverleaf whitefly has been responsible for over $400 million in losses to growers in southern California. The objective of the present study is to increase the diversity of natural enemies through importation, mass rearing, release, and establishment of exotic parasitoids in agricultural, urban, and natural field sites in the Imperial Valley. In the first year of this three year project we introduced *Amitus bennetti*. Releases began in June of 1994 and we released over 366,000 *A. bennetti* into the Imperial Valley. Beginning in August 1994 we began post-release evaluation for *A. bennetti* establishment and have recovered *A. bennetti* from two of the urban release sites. *A. bennetti* were recovered at only one agricultural site. Currently, we are in the second year of the program and are introducing *Encarsia* n. sp. into the Imperial Valley. This parasite is native to India and is adapted to hot dry environments.

Releases of *Encarsia* n. sp. began in September 1995 and to date we have released over 60,000 individuals into the Imperial Valley. We began post-release evaluation for *Encarsia* n. sp. in November 1995. Leaf samples were collected from field sites (usually 10 leaves after visual inspection). We have made recoveries of *Encarsia* n. sp. at 20% of our urban sites. Recoveries have not been made at agricultural sites as of yet. Extensive releases of *Encarsia* n. sp. have been made into melon and cotton growing areas.

Pre-release surveys in the Imperial Valley indicated that only one parasite species, *Eretmocerus* sp. nr. *californicus*, is currently causing substantial parasitism of silverleaf whitefly. In other areas of North America the silverleaf whitefly is a less injurious, but several parasitoid species (up to ca. 10) are typically present. Thus, we feel that increasing the diversity of natural enemies attacking the silverleaf whitefly in the Imperial Valley will aid in the overall control of this pest.

Investigator's Name(s): K. A. Hoelmer.

Affiliations & Locations: USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: March 1996 to December 1996.

1996 Field Cage Evaluations of Non-indigenous Parasitoids in Desert Crops

Evaluations of introduced parasitoids of *Bemisia* have been conducted to identify species that are more effective than native species against silverleaf whitefly in desert valleys of California and Arizona. These studies were continued in 1996. Parent material maintained in culture at the USDA Mission Biological Control Center in Mission, TX, and the California Department of Food & Agriculture in Sacramento was obtained for studies. Each culture has been characterized with a diagnostic PCR pattern by the Mission laboratory.

Replicated cage trials were conducted by releasing *Bemisia* into mesh-covered 6x6x6 ft field cages containing field-sown cotton seedlings or melon, broccoli or alfalfa seedlings transplanted from the greenhouse, depending on the crop evaluated. When nymphs of suitable age were present (2nd & 3rd instar for *Eretmocerus,* 3rd and early 4th for *Encarsia*), known numbers of female parasitoids were released into each cage, accompanied by males for mating. The development of their progeny was monitored to determine when cages would be sampled. Non-release cages served as controls and provided an estimate of the level of contaminating parasitism. Samples were taken to compare production of F_1 progeny and again after the second generation to compare continued increase in numbers.

Evaluations in spring cantaloupes compared the *Eretmocerus* spp. M95012 (Pakistan, Eret-10), M95097 (Taiwan, Eret-3), M95098 *nr. furuhashii* (Taiwan) and M95104 (United Arab Emirates, Eret-11) and the uniparental *Encarsia* M95001 (Dominican Republic, unique PCR pattern) and M94056 (Brazil, En-16). In cotton, the same species were evaluated during the summer except for the elimination of *Encarsia* M94056 (whose evaluation on all 4 crops was complete). Trials of *Eretmocerus* M95097 (Taiwan), M95098 *nr. furuhashii* (Taiwan) and M95104 (United Arab Emirates) and *Encarsia* M95001 (Dominican Republic) in broccoli and alfalfa were begun in October and are still in progress.

In the spring melons, all of the *Eretmocerus* species or populations produced more F_1 progeny than either of the uniparental *Encarsia* species (mean progeny/female, followed by range: M94056, 5.78 (4.94-6.56); M95001, 0.93 (0.38-1.66); M95012, 9.22 (6.76-10.56); M95097, 18.14 (11.74-25.48); M95098, 10.11 (6.64-14.32); M95104, 20.77 (13.68-27.38). Contamination by native *Eretmocerus* and *Encarsia,* as measured in the control cages receiving no releases of parasites, was very low following the F_1 generation. The second sample following the F_2 generation indicated that M95104 continued to reproduce very well on melons. M95012 produced the second-largest number of progeny during the F_2 generation, while the remaining species/populations failed to increase appreciably after the F_1 generation, suggesting that they are not well-adapted for either the crop or the climatic conditions in desert valleys.

Results for the cotton evaluations were complicated by high levels of contamination from invading *Eretmocerus.* Nearly all of the contamination was due to *Eretmocerus* M95104 (UAE), presumably from the earlier melon tests conducted in the same field. For this to occur, the contaminating parasitoids had to escape from closed melon field cages and invade the closed cotton field cages in significant numbers. Although this was an undesirable outcome for the evaluations on cotton, it suggests that *Eretmocerus* M95104 has the dispersal and host-finding capabilities needed for an efficient biological control agent.

Investigator's Name(s): K. A. Hoelmer[1], W. J. Roltsch[2], J. Gould[3] & G. S. Simmons[4].

Affiliations & Locations: USDA-APHIS, Phoenix Methods Center, Brawley CA[1] & Phoenix AZ[3]; CDFA, Biological Control Program, Brawley CA[2], and USDA-APHIS, Western Region, Brawley CA[4].

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January 1996 to December 1996.

Overwintering & Dispersal of Non-indigenous Parasitoids Released in CA & AZ Desert Valleys

As of December 1996, introductions into Imperial and Riverside Counties, CA and Maricopa, La Paz and Yuma Counties, AZ, have been made of 32 non-indigenous parasitoid collections and one predatory coccinellid maintained in cultures at MBCL in Mission, TX. Many of these represent different geographic populations of a smaller number of distinct species (16 different PCR patterns are represented among the parasitoids introduced). Some of the cultures found to be effective in field evaluations against whiteflies on desert crops have been released in large numbers. Five different non-indigenous *Eretmocerus* and two *Encarsia* PCR patterns have been released in numbers exceeding 250,000. Two of the *Eretmocerus* PCR types have been released in numbers greater than 5 million individuals.

Many of the *Encarsia* and *Eretmocerus* populations released in 1995 & 1996 reproduced and dispersed locally near the release site. For permanent establishment, recoveries which demonstrate overwintering and dispersal from the original release site are more significant. A number of such positive finds were recorded during early 1996 from recovery samples.

Non-indigenous parasitoids were recovered in 1996 in survey collections from a number of sites in the communities of Brawley and El Centro. These included specimens of *Eretmocerus* at several locations where releases were made during 1995. At two of the sites, large numbers of specimens were recovered from cole crops and the exotic *Eretmocerus* comprised a high proportion (up to 95%) of the total number reared.

Recoveries of overwintering exotic *Eretmocerus* (ERET-1) were also made in Phoenix. Large numbers of the exotic species constituted a majority of *Eretmocerus* specimens reared from collards in a refuge planting. This *Eretmocerus* was also recovered from whitefly on hibiscus, lantana, cape honeysuckle and sowthistle up to one-half mile from the release site.

Positive finds were made in Imperial Valley samples collected in agricultural crops some distance from urban release sites. These recoveries included exotic *Eretmocerus* at 3 different sites located miles from each other and from the nearest urban populations. One recovery collected in March from whitefly on collards was in an area where the last previous release occurred in spring melons in 1995. Recoveries were also made from whiteflies in 2 spring melon fields, located 2 and 4 miles, respectively, from the nearest possible release or rearing source. The recovered parasitoids came from overwintering populations originally collected from the Mediterranean (PCR pattern ERET-1) and/or Pakistan (ERET-10).

Recoveries of another *Eretmocerus* from Thailand (M94023, ERET-3) were made from collards in a CDFA refuge plot in Brawley where large numbers were released in 1995.

These recoveries are a promising indication that establishment of some of the introduced species is occurring. Finding introduced *Eretmocerus* in cole crops in large numbers is especially encouraging because these crops are not good hosts for the indigenous *Eretmocerus*.

Investigator's Name(s): K. A. Hoelmer.

Affiliations & Locations: USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: August 1995 to December 1996.

Parasitism of Silverleaf Whitefly in Alfalfa

The 180,000 acres of alfalfa in the Imperial Valley, CA, represents a potentially large reservoir for natural enemies of *Bemisia*. Studies of whiteflies in alfalfa during 1995 and 1996 showed that parasitized 4th instar whiteflies were first found in low numbers in late spring. Significant levels of parasite activity occurred at some locations by fall when whiteflies were most abundant. Both native and non-indigenous parasitoids in the genera *Eretmocerus* and *Encarsia* were capable of successful development to emergence in whiteflies on this crop. In our samples, most of the naturally-occurring parasitism was due to native *Eretmocerus* rather than *Encarsia*.

The influence of frequent cuttings on the levels of parasitism and on the distribution of whiteflies and parasites on alfalfa above and below the cut level was examined in three alfalfa plots cut at different schedules. Whitefly and parasitoid populations in commercial fields were also examined by sampling fields from areas cut at standard intervals (between section borders or on rows depending on culture type), from section borders (typically cut higher to avoid damaging berms) and inside furrows and along edges of fields that escape cutting.

Frequent cutting cycles do reduce the parasitism in alfalfa. Cutting generally removes all stems and foliage above 2-4 inches, and a large proportion of the whiteflies and parasitoids as well. However, we found that substantial amounts of whitefly-infested alfalfa escape cutting along the edges of section borders, within furrows and along field edges. Thus, we remain optimistic that the substantial acreage of the crop may be a significant reservoir for natural enemies of *Bemisia*. We are continuing to survey commercial alfalfa fields to provide more information on the suitability of alfalfa as a reservoir for parasites.

To date, several hundred thousand *Eretmocerus* M92014 (Spain), M94120 (Israel), M95012 (Pakistan), M95104 (United Arab Emirates) and *Encarsia spp.* M92018 (India), M93003 (Spain), M95055 (Brazil) have been released in alfalfa at several locations at the Salton Sea National Wildlife Refuge beginning in late June of 1996. This acreage is managed for migrating waterfowl and treatment with insecticides is minimal. The refuge is surrounded on three sides by commercial agriculture and provides a good site for establishing and building large populations of introduced natural enemies which can then migrate outwards.

Investigator's Name(s): K. A. Hoelmer and G. Culver.

Affiliations & Locations: USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January 1996 to December 1996.

Survey of Desert Host Plants for Whiteflies and Parasitoids

An earlier survey to identify desert host plants of silverleaf whitefly in Imperial County, CA, has been continued and expanded to include other whitefly species on native and introduced desert plants and urban ornamentals in order to identify the parasitoids which attack them. This information may be useful in documenting the non-target impact of introduced whitefly parasitoids in addition to providing information on their host reservoirs for biological control.

Over 50 desert sites established for the earlier survey continue to be inspected several times per year for whiteflies which, if present, are sampled to determine species and parasitism. Locations in Arizona have also been sampled. Collections over the past 3 years have documented ca. 21 species of desert plants which are the most frequent hosts of *Bemisia argentifolii, Trialeurodes abutiloneus* and several species of *Aleuropleurocelus*. Parasitoids have been reared from whiteflies on fourteen of these host plants. Preliminary identifications of the parasitoids include more than 5 species of *Encarsia*, at least 2 species of *Eretmocerus* and one or more species of the eulophid *Neopomphale*. These include *Eretmocerus sp. nr. californicus* (desert CA/AZ species), *Encarsia luteola* and *Enc. meritoria*, the three species which attack silverleaf whitefly in desert crops.

Urban host plants on which non-target whiteflies are found include several species of tree: Arizona ash, carob, carrotwood and mulberry; and the shrubs lantana and vining rose varieties. Non-target whiteflies found on these hosts include *Tetraleurodes mori*, *Tetraleurodes acaciae* and *Siphoninus phillyreae* on tree species and an unidentified species of *Aleuropleurocelus* on lantana. *Encarsia inaron* has been reared from *Siphoninus phillyreae* on ash trees.

Silverleaf and bandedwinged whiteflies are typically found on the same host plants, sometimes in mixed populations. The *Aleuropleurocelus* species are usually found on different hosts than these two species; lantana being a prominent exception. The group of parasitoids attacking silverleaf whitefly are nearly the same as those reared from *Trialeurodes abutiloneus*. Parasitoids reared from *Aleuropleurocelus* species appear to be entirely different. No introduced species of *Eretmocerus* and *Encarsia* have yet been identified in rearings from non-target species or from any of the desert collection sites. These results are preliminary since many specimens recovered have not yet been unexamined.

Investigator's Name(s): M. S. Hunter and S. K. Johnson.

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the Report: August - November, 1996.

Interactions of an Exotic Autoparasitoid and a Native Primary Parasitoid: Preliminary Investigations

Whitefly parasitoids have diverse reproductive biologies. While species in the genus *Eretmocerus* are primary parasitoids, most commonly females of *Encarsia* species develop as primary parasitoids of whiteflies, while males are hyperparasitoids and may develop on immature females of their own species or on other primary parasitoids in the parasitoid complex. *Encarsia* species with this unusual biology have been involved in the successful biological control of the citrus whitefly and the citrus blackfly. Little research has yet investigated the interactions between whitefly parasitoids with different life histories. However, this is a system in which the range of expected interactions between parasitoids include not only competition but direct parasitism of one parasitoid by another. The value of autoparasitoids to biological control has long been a subject of controversy. On the one hand it has been suggested that the density dependent mortality of autoparasitoids may increase the stability of the parasitoid complex. However, it has also been suggested that autoparasitoids' ability to use other parasitoids as hosts for males may give them unassailable competitive superiority in parasitoid complexes and preclude the establishment of other species which might provide better regulation of the host.

We are examining the effects of interactions between an exotic autoparasitoid, *Encarsia transvena* (Timberlake) (population from Spain, Mission Biological Control Laboratory Quarantine no. M93003), and a native primary parasitoid, *Eretmocerus* nr. *californicus* (AZ) on biological control of whitefly in laboratory and field experiments. In our first experiments, we have investigated the effects of mating status and secondary host species and stage on the oviposition behavior of *E. transvena* females.

Expt. 1. Oviposition behavior of mated and unmated female *E. transvena* in whitefly nymphs.
Generally, unmated autoparasitic *Encarsia* females do not oviposit readily in whitefly nymphs, the host for female progeny. However, unlike most *Encarsia*, *E. transvena* males develop as ectoparasitoids of the parasitoid host. We thus wanted to determine whether *E. transvena* females oviposit male eggs in whiteflies in anticipation of the whitefly hosts being consumed by primary parasitoids. This biology has been recorded for other heteronomous aphelinids.

Our three treatment groups were females that had been observed to mate, unmated females that were held (like mated females) in isolation, and unmated females that were held in groups of three. Our thinking was that oviposition of male eggs in anticipation of parasitism, if it occurred at all, would be more likely to occur if unmated females experienced contact with other adult females. All females were 24-72 h old when they were placed in 35 mm petri dishes containing a leaf disk with 30 N3-early N4 Trialeurodes vaporariorum nymphs. After 48 hours the females were removed, and the arenas were refrigerated. All hosts were dissected and the number of eggs and larvae recorded.

No eggs were laid in whiteflies by unmated females (n = 20, number of whiteflies dissected = 600). All of the mated females (n = 10) laid eggs; on average 8.4 ± 0.99 (SE) eggs were laid in 7.4 ± 0.85 (SE) hosts.

Expt 2. Secondary host selection by *E. transvena* females
We examined host selection behavior of female *E. transvena* among parasitoid hosts. Pairwise choice tests were performed among three types of hosts: *E. transvena* late larvae and prepupae, *E. transvena* early pupae, and *Eretmocerus* nr. *californicus* prepupae and early pupae. Hosts were presented on leaf disks on filter paper in 35 mm petri dish arenas; five hosts of each type were placed in each arena. Newly emerged females were confined with males for 24 h and then introduced singly to the arenas for 24 h. All arenas were then refrigerated, and the hosts dissected.

Females parasitized significantly more *Eretmocerus* than *E. transvena* early pupal hosts (0.96 of the hosts parasitized). When given a choice between *Eretmocerus* and *E. transvena* larval to prepupal hosts, however, females did not parasitize one host significantly more than the other (0.65 of the hosts parasitized were *Eretmocerus*). When the two *E. transvena* stages were presented, females parasitized more of the larval to prepupal hosts (0.90) than the pupal hosts. These results suggest that secondary host species selection by *E. transvena* is stage dependent.

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Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Biology of *Dereocoris nebulosus* (Heteroptera: Miridae) on *Bemisia*

Deraeocorus nebulosus (Uhler) is a common predaceous plant bug occurring throughout most of North America. It is found in tree, shrub and row crop habitats. Its hosts are mainly slow-moving Homoptera and Heteroptera, including aphids, mealybugs and whiteflies. It becomes common in commercial cotton fields infested with whiteflies in Mississippi when whiteflies are often the only available host. Breeding populations maintain themselves under regular regimes of insecticide pressure. This represents an initial investigation to record basic biological aspects of this species when fed only immature *Bemisia*. Development rate and daily female fecundity were recorded.

Nymphs were collected from cotton in or around Stoneville, MS during October, 1996. The progeny of the resulting adults were used to record development through each instar at 27°C. Insects used for these studies were placed individually in large, ventilated Petri dishes, each containing an excised, rooted sweetpotato leaf infested with *Bemisia* immatures from a colony collected in Weslaco, TX. For fecundity and longevity, individual females with one or two males, were used. Leaves were changed once every few days, before hosts were depleted. Eggs were deposited in leaf petioles and in the larger leaf veins. Eggs were counted daily. Duration of each of the five nymphal instars was 2.6, 2.0, 2.2, 2.4, and 4.1 days, respectively. Mean development from first instar to adult (using only those surviving to adult) was 13.3 days. There was no significant difference by sex. There was a 2-5 day preoviposition period. Female longevity ranged from 1-44 days. Each female produced a mean total of 204.5 eggs, ranging from 0-31 per day. Testing is continuing.

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Research & Implementation Area: Section D: Biological Control

Dates Covered by the Report: 1996.

Evaluation of *Eretmocerus* spp. on Tomato

The local south Texas species of *Eretmocerus* (ms. name *tejanus* Rose and Zolnerowich) has been observed to not prefer to forage on tomato. Two *Eretmocerus* spp. were found controlling *Bemisia tabaci* on staked tomato in Taiwan in 1995. Both Taiwan spp. were subsequently collected and imported for evaluation. Three separate experiments were conducted among these and other *Eretmocerus* spp. to evaluate their potential for managing *Bemisia* on tomato. The first consisted of a greenhouse screening test, evaluating five *Eretmocerus* spp.: the local south Texas species (M94003), *E.* sp. nr. *furahashii* (Tainan, Taiwan; M95098), *Eretmocerus* sp. (Tainan, Taiwan; M95097), *Eretmocerus* sp. (Multan, Pakistan; M95105), and *E.* sp. nr. *mundus* (Murcia, Spain; M92014). Parasitism was assessed on potted plants using individual female parasitoids placed in single-leaf sleeve cages containing whitefly immatures of equal ages. Parasitism rate was highest in the Spanish *Eretmocerus*, and lowest in the Texas *Eretmocerus* sp., but the differences were not significant, probably attributable to high variation among individual females.

In a separate test, developmental time was studied and compared between the two Taiwan *Eretmocerus* spp. and the local Texas species. Development time at 27°C differed significantly across each species: *E.* sp. nr. *furahashii* took just under 15 d; *Eretmocerus* sp. (Taiwan, M95097) took slightly over 15 d, while the Texas *Eretmocerus* took over 17 d. There were no differences by sex within species.

A third experiment was designed to compare various foraging behaviors between *E.* sp. nr. *furahashii* and the local Texas *Eretmocerus*. An individual, newly emerged, mated, female was released onto an infested tomato leaf and videotaped for up to one hour. Significantly more Texas *Eretmocerus* sp. left the leaf in the first minute. Among individuals that chose to forage, there were no significant differences between the two species in number of hosts attacked, total time on leaf, oviposition time, and post-oviposition preening. Only host feeding differed significantly, from a mean of 12.5 min in *E.* sp. nr. *furahashii* versus 3.8 min in the *Eretmocerus* sp. from Texas. Several ovipositions occurred before either species began to host feed.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: June 1995 - December 1996.

Field Cage Evaluation of *Amitus bennetti* (Hymenoptera: Platygasteridae), a Parasitoid of *Bemisia argentifolii*

The parasitoid *Amitus bennetti*, originally collected in Puerto Rico, was released in the Imperial Valley, California, as part of a biological control program for *Bemisia argentifolii*. There was limited establishment of the parasitoid, with approximately 150 adults recovered. A field cage evaluation of *A. bennetti* was conducted on cotton (*Gossypium hirsutum* L.) in Riverside at the University of California Experiment Station. A cohort of approximately 100 nymphs were marked in the control and treatment/release cages that contained the parasitoid. The status of the nymphs was monitored twice per week, and the mortality factors: death, disappearance, and parasitism were recorded. Life tables were constructed for *B. argentifolii* in both the control and release cages. There was 34% mortality of *B. argentifolii* in the control cages. The release cages with *A. bennetti* had 62% mortality. A similar experiment was conducted in bean (*Phaseolus vulgaris* L.). The bean control cages had 25% mortality of *B. argentifolii*, while the release cages with the parasitoid had 72% mortality of the whitefly.

The laboratory biology of *Amitus bennetti* was also investigated on cotton (*Gossypium hirsutum*). The average development time at 28 ∞C from egg to adult for *A. bennetti* was 21.4 days (range of 18-31 days). Total fertility, daily fertility, and longevity were measured. *Amitus bennetti* that were offered new hosts daily lived an average of 6.3 days (range of 3-11 days). The average number of adult progeny produced by these parasitoids was 78.78 (range of 47-122). The majority of adults emerged from hosts that *A. bennetti* encountered on the first day of the study. The total fertility of *A. bennetti* was investigated by confining the parasitoid to one cotton leaf with sufficient whitefly nymphs for her entire life. The average longevity was 6.3 days (range of 4 to 8 days). The average number of adult progeny produced was 56.11 (range of 15-110 adults).

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: January 1996 - January 1997.

Exploration for Natural Enemies and Evaluation of *Paecilomyces fumosoroseus* and the Cocinellid *Clitostethus arcuatus*

Collections were made in Sicily, southeastern Pakistan and Malaysia. *Eretmocerus* sp. dominated the heavily sprayed material from Sicily. *Encarsia lutea* was reared from a wild *Solanum* sp. and transferred to the UC Riverside quarantine. Very large numbers of *E. transvena* emerged from a comprehensive collection made in Vehari southeastern Pakistan. Additional large numbers of the *Eretmocerus* sp. adapted to WF on cotton also emerged.

Using a modified spray system operating at 6 bars pressure the pathogenic fungus *Paecilomyces fumosoroseus* was applied in water to second and third stage silverleaf whitefly nymphs on tomato and cucumber in a greenhouse. Three experiments were carried out. Conditions were kept at 25°C and %RH was maintained at close to 100 for 24h after application. Control plants were sprayed with distilled water. A 25-63% kill of nymphs was obtained suggesting that this method has potential for use in controlled atmosphere greenhouse cultivation.

The specificity of *Clitostethus arcuatus* (Coleoptera: Coccinellidae) was tested using adults of 2 whitefly species and the nymphs of an aphid of the same size, offered in two forms of arena. An aerated petri dish arena containing a cabbage leaf disc onto which the prey insects and the predator were introduced. Although simple and easy to use the system was not appropriate for adult whiteflies as condensation and static electricity caused high mortality. A rooted single leaf of cabbage enclosed in a cellophane bag (which allowed air movement through the membrane and was not subject to static charge) eliminated mortality of whitefly adults due to condensation and static.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Use of *Beauveria bassiana*, an Entomopathogen to Control Nymphs of *Bemisia argentifolii* Under Field, Laboratory, and Greenhouse Conditions

Efficacy of *Beauveria bassiana* on *Bemisia argentifolii* was tested under field, laboratory and greenhouse conditions. For the field test on eggplant conducted in 1995, raised beds 91 cm wide on 180 cm center were fertilized and maintained using standard practices 3 wk before setting transplants at 51 cm spacing. Eggplant rows were divided into plots 6.5 m long, separated at either end by a 1 m buffer and arranged in a completely randomized block design with 8 replications and 2 treatments: 5 weekly sprays from 21 April until 7 May 1995 of Mycotrol WP9504 (Mycotech Stain GHA spores, 22%, 4.4 x 10^{10} spores/g; Mycotech, Butte, MT) at rates of 1.1 kg/ha (1 lb/ac) and an untreated check. Weekly samples for *B. argentifolii* immatures from 24 April consisted of a single leaf from 3 randomly selected plants from the 6th or 7th leaf from the terminal per plot, collected into plastic zip-lock bags, and brought back to the laboratory. Whitefly immatures (eggs, nymphs and pupae) were examined on four 1-cm^2 disks, 2 on each side of the mid-vein. Eggs, young (1st and 2nd instar) and old (3rd and 4th instar) nymphs and pupae (red-eyed nymphs) of *B. argentifolii* on 12 cm^2 leaf area were counted under a stereo microscope in the laboratory. In laboratory bioassays, 3 wettable powders: Mycotrol WP, WP9503, and WP9504, each with Silwet L-77 (0.03%) were tested with Silwet L-77 (0.03%) and water as controls. The rate for the 3 wettable powders was 10^8 spores/ml as recommended. The test was conducted in an air-conditioned insectary under photo period of L:D = 14:10 h at 25 ± 2°C. RH at the first 24 h after treatment was maintained at 100% by covering all treated leaves in a transparent plastic bag with a water pan using, and RH was maintained at 65 ± 5% with thereafter. Hibiscus leaves bearing first instars of whitefly nymphs were sprayed using the Potter Spray Tower, and 3.0 ml dilutions sprayed with an air pressure of 10 psi. For greenhouse tests conducted in a large cage (80 x 80 x 240 cm), the commercial product, Mycotrol ES (2.1 x 10^{10} spores/ml), was tested against *B. argentifolii* nymphs on 2 cultivars of hibiscus, "Versicolor Pink", and "Brilliant red". Rates used were 2.5 (2.1 x 10^{10} spores/ml) and 1.25 ml/liter (1.05 x 10^{10} spores/ml), and water as a control. Hibiscus plants used were approximately 30-40 cm high with 2-4 branches and 6-9 fully expanded leaves. Old and small leaves were removed, and only the top fully expanded young leaves were used. *B. argentifolii* eggs were obtained by introducing whitefly adults (40 adults/leaf) for oviposition, and the whiteflies were removed 4 h later. *B. argentifolii* eggs were allowed to hatch, and the nymphs were allowed to develop for 4-5 d. Leaves bearing 1st (≈70%) and 2nd (≈30%) instars of whitefly nymphs were sprayed to run-off using a hand plastic Spritzer. After drying, plants were reconfined in the cage. Relative humidity (RH) inside the cage after treatment was maintained at >95% by using a mist system misting 10 min at an hourly interval during the daytime (between 7:00 a.m. to 7:00 p.m.). Leaves bearing treated whitefly nymphs were collected from the plants 10 d after treatment, and live and dead nymphs were examined under a stereo microscope.

In the field test, numbers of *B. argentifolii* nymphs and pupae on leaves of tomato and eggplant were not significantly different from untreated plants, although *B. bassiana* infested pupae (red pupae) were found on treated plants. Infected pupae on eggplant was 40.7%, and on tomato, 50%. In the laboratory bioassays, mortality of whitefly nymphs was high from all treatments of *B. bassiana*, as well as the treatment of Silwet L-77. Red nymphs were seen on 2nd, 3rd, and 4th instar nymphs and pupae (red-eyed nymphs), indicating infection by the fungus. There were no red 1st instar nymphs found, apparently because death occurred before the fungus could grow or develop sufficiently. Mortality of whitefly nymphs treated with the fungus reached 93.6%. Overall number of red nymphs increased on day 15 than on day 8. In the large cage-greenhouse bioassay, percentage mortality of whitefly nymphs was relative high in all treatments of *B. bassiana*. Red nymphs were seen on second, third, and fourth instar nymphs (including pupae), indicating infection by the fungus. Generally the percentage was greater at the higher rate than the lower rate, although the different was not significant. Mortalities were also generally greater on "Versicolor Pink" than on "Red Brilliant" even though the difference was not significant. Results from these tests clearly indicated a potential for *B. bassiana* as a mycoinsecticide for *B. argentifolii* nymphs under confined conditions where high relative humidity could be provided.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1996.

Functional Response of *Nephaspis oculatus* (Coleoptera: Coccinellidae) to Egg Density of *Bemisia argentifolii*

Bemisia argentifolii was maintained in an air-conditioned greenhouse on collard. Uninfected collard leaves were exposed to the whitefly colony for a 24 h oviposition period. Disks were cut from the egg-bearing leaves and excess eggs removed with a probe using a stereo microscope to obtain the desired egg density. Disk size and egg densities tested varied with life stage of ladybeetle being evaluated and are given below. Leaf disks were placed ventral-side-up on water-saturated filter paper in clear plastic petri dishes into which the coccinellids were introduced singly. Experiments were conducted in an air-conditioned insectary at 26.7 ± 2°C , and 55 ± 5% RH. Photoperiod was set at l4:10 (L:D) h. Sexed *N. oculatus* adults collected from the greenhouse culture were starved for 24 h in glass vials (6 x 0.5 cm) before introduction singly into 5 x 1.5 cm petri dishes containing an infested collard leaf disk 5 cm in diameter (19.6 cm^2). The 6 prey densities tested were 20, 50, 100, 200, 300, and 400 eggs per leaf disk with 20 replicates for each density and sex. Beetles were removed from the leaf disk after 24 h and the number of eggs attacked (completely or partially eaten and damaged) was determined under a stereo-microscope. Leaf disks were discarded if the beetle died or did not eat. Cohorts of *N. oculatus* eggs were obtained by exposing infested collard plants to caged coccinellids. *N. oculatus* eggs were allowed to hatch, and larvae were allowed to develop to the required instar. Collard leaf disks measured 1 cm diameter (0.79 cm^2) for 1st instars, 2 cm diameter (3.14 cm^2) for 2nd instars, and 3 cm diameter (7.0 cm^2) for 3rd and 4th instars. Larvae were starved in small petri dishes (2.5 x 0.5 cm) for 4 h before use. A larva was then introduced singly onto the leaf disk bearing 5, 10, 15, 20, and 30 for 1st instar; 20, 40, 60, 80, and 100 for 2nd instars; 20, 50, 100, 150, and 200 for 3rd and 4th instars inside 5 x 1.5 cm petri dishes except for 1st instars for which a smaller (1.5 cm) dish was used. Each instar/density combination had 11-24 replicates.

Regression analysis of percent eggs consumed as a function of egg density indicated a strong linear relationship for 1st instar (r^2 = 0.90), 2nd instar (r^2 = 0.94), and adults (male: r^2 = 0.91; female: r^2 = 0.99), but less so for 3rd instar larvae (r^2 = 0.82) and 4th instar larvae (r^2 = 0.64). Most predators attacked all or most prey provided at lower prey densities, but were less thorough with more variable results at higher prey densities. Mean number of *B. argentifolii* eggs attacked by a *N. oculatus* increased with prey density during the 24 h period. A good fit was observed between functional response curves for all stages and the type II model of the Holling's disc equation. Among the developmental stages of *N. oculatus*, adult females consumed and killed the most whitefly eggs at each prey density. The model would predict a maximum of 321 whitefly eggs per day could be attacked by an adult female, 237 per day by an adult male; and 34, 73, 229, and 312 eggs per day by a 1st, a 2nd, a 3rd, and a 4th instar larva, respectively.

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Research & Implementation Area: Section D: Biological Control.

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January - November 1996.

Parasitization of silverleaf whitefly by *Eretmocerus* sp. (Hong Kong) on collard, *Brassica oleracea*, genotypes differing in leaf epidermal wax

The parasitization efficiency, survival and development of *Eretmocerus* sp. (a thelytokous species introduced from Hong Kong in 1992) was evaluated on 'Green Glaze' collard, *Brassica oleracea* var. *acephala*. This cultivar segregated for normal wax and glossy genotypes. Previous research by Farnham, Elsey and Jackson indicated that glossy crucifer cultivars (with reduced wax bloom and therefore a 'glossy' or 'shiny' appearance) were less preferred than normal wax cultivars for whitefly oviposition. We wished to determine whether variation in leaf epidermal wax would affect parasitism by *Eretmocerus*.

None of the parasitoid's life history parameters measured in these experiments differed on the normal wax and glossy collard genotypes. Life time fecundity, developmental period and survival from parasitization to parasitoid emergence were similar on both genotypes. In choice and no-choice tests, parasitoids parasitized similar proportions of whiteflies on both genotypes. These studies indicate no incompatibility between plant resistance (glossiness in crucifers) and biocontrol by an *Eretmocerus* sp.

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January - November 1996.

Parasitization of silverleaf whitefly by *Eretmocerus* sp. (Hong Kong) on soybean isolines differing in pubescence

The parasitization efficiency of *Eretmocerus* sp. (a thelytokous species introduced from Hong Kong in 1992) on silverleaf whitefly was evaluated on three soybean isolines varying for pubescence. Isolines were glabrous (no hairs), pubescent (2.9 hairs/mm^2) or densely pubescent (17.4 hairs/mm^2). Two experiments were conducted in the laboratory. In one experiment parasitoids could choose where among the three isolines to search for whitefly hosts (choice test), while in the second experiment parasitoids were confined to a single soybean isoline (no-choice test).

Eight plants of each isoline were infested individually with 50 pairs of whiteflies. Whiteflies were removed after three days, and one plant of each isoline was placed in a screened cage measuring 60 x 60 x 60 cm (choice test). Fifteen parasitoids were added to each cage when first instar whiteflies were present. Six weeks later, foliage was removed and exuviae with parasitoid or whitefly emergence holes were counted. Analysis of variance performed using whiteflies as a covariate indicated that significantly more parasitoids emerged from pubescent (277 ± 22 per plant, mean ± SEM) and glabrous plants (214 ± 35) than from hirsute plants (151 ± 25).

For the no-choice test, soybean plants were individually infested with whiteflies in 30 x 60 cm cylindrical cages. Whiteflies were removed after 3 days. Five parasitoids were added to each plant when first instars were present. Four weeks later, foliage was cut from the plants and exuviae with parasitoid or whitefly emergence holes were counted. Analysis of variance indicated no significant differences among the isolines, however more parasitoids emerged from the glabrous (202 ± 35) and pubescent (206 ± 40) plants than from hirsute (132 ± 16) plants.

Experiments are being repeated and studies are underway to determine the behavioral mechanisms responsible for reduced parasitism on the hirsute soybean isoline.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: December 1995 - December 1996.

Enabling Biologically Based IPM on Cotton: Impact of Conventional Insecticides vs. Insect Growth Regulator Buprofezin (Applaud®) on Parasitoid Populations

In a research project in cooperation with Pacheco Farm in Marana (near Tucson, Arizona), we focus on three objectives: (1) to develop an environmentally friendly, effective and economically feasible pest management program for cotton in the Marana region; (2) to reduce the frequency of insecticide applications through the use of multiple control tactics; (3) to conserve natural enemies and make optimal use of natural control in cotton. Pink bollworm, *Pectinophora gossypiella*, and whiteflies, *Bemisia* sp., are the two key pests here. The greenhouse whitefly, *Trialeurodes vaporariorum*, was abundant during April and May but disappeared in June.

In the 1996 season, we compared the effects of two chemical control treatments, conventional versus IGR regime, in large scale plots on field CalMat East-6 (plot size was about 3.5 acres; four replicates). IGR's were an important building component of a resistance management program for whitefly in Arizona cotton (see the extension publication UA IPM Series 4 by Dennehy *et al.* 1995). The main question was whether the use of IGR's would allow for higher levels of parasitism than conventional insecticides and whether the use of IGR's would then lead to lower whitefly densities because of a higher natural enemy abundance.

Transgenic *Bt*-cotton was planted and no insecticide applications were needed against pink bollworm. We sampled whiteflies (adults, nymphs and pupae) and parasitic wasps (parasitized nymphs and pupae) in the center of each plot on a weekly basis. We followed the sampling procedures and recommendations on action thresholds set forth in UA IPM Series 2 and 6 (Ellsworth *et al.* 1995, 1996). Only one insecticide application was necessary during the entire season: a combination of Thiodan® and Ovasyn® in the conventional plots and buprofezin (Applaud®) in the IGR plots. Levels of parasitism were generally low with the highest average level at about 17% in the IGR plots on August 17. There were no statistically significant differences in parasitism or whitefly densities between the conventional and IGR treatment at all sampling dates (Analysis of Variance test). The effects of an IGR on parasitic wasp populations did not appear to be different from those of a conventional application. Note that weather conditions such as heavy rain storms or product formulation cannot be excluded as a cause of the relative decline in parasitoid numbers.

Compared with previous years with 4 to 6 applications per year, the planting of transgenic cotton and the implementation of recommended sampling procedures and action thresholds contributed to a substantial reduction in insecticide use in field E.-6 in 1996 (only one application; see objective 2).

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: November 1995 - November 1996.

Mass-Rearing Native and Exotic *Eretmocerus* Wasps for Whitefly Biological Control in Greenhouse and Field Crops.

With regard to mass-rearing the native *Eretmocerus* (Arizona) wasps, we produced 31.3 million pupae over the past year and shipped over 7.5 million *Eretmocerus* pupae in 267 batches to various cooperators (funded by Beneficial Insectary). Various laboratory and greenhouse studies (1993-1996) have shown that inundative releases of the native *Eretmocerus* are providing effective whitefly control in greenhouse crops. Some growers in Europe began using this wasp as a biological control agent in 1993, especially in crop situations where some insecticides are being applied or under warm weather conditions. In the U.S.A., biological control of *Bemisia* whiteflies on poinsettias employing *Eretmocerus* is close to implementation by growers, although costs are relatively high compared with current chemical control regimes.

Because *Eretmocerus* from Arizona is now available from three commercial producers (viz., Koppert Biological Systems, Ann Arbor, MI; CIBA Bunting North America, Oxnard, CA; International Technology Services, Boulder, CO), we decided to terminate the pilot mass-rearing at the Univ. of Arizona Campus Agricultural Center in November. Wasps will continue to be available for research purposes through these companies.

With regard to rearing exotic *Eretmocerus* spp., we initiated a production of a strain from Israel (# M94120) and one from India (# M92019) as part of a cooperative biological control project with USDA-APHIS and the Arizona Cotton Research & Protection Council. We acquired starter colonies from USDA-APHIS, Mission BioControl Laboratory, TX (courtesy Drs. J. Goolsby & L. Wendel). We used the same rearing technology proven to be highly efficient for the native wasps. We made a few adaptations e.g., the rearing host is the same as the target pest, *Bemisia* whiteflies. Since the end of August we have been producing approximately a quarter million pupae per week with an average return of 3.6 fold increase per generation. A few million exotic wasp pupae will have been introduced in Arizona this year as part of this large-scale classical biological control program. Results on identification, establishment and evaluation of these exotic whitefly parasitoids are presented elsewhere.

Investigator's Name(s): Steven E. Naranjo & James R. Hagler.

Affiliations & Locations: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: April 1996 - October 1996.

Conservation of *Bemisia* natural enemies in relation to conventional and IGR-based management systems

A large-scale (» 80 hectares), multi-institutional (UA, ARS-Phoenix, ARS-College Station) experimental study was initiated in 1996 to examine and demonstrate strategies for *Bemisia* management involving the use of two insect growth regulators (IGR) granted section 18 status in Arizona. The study involved three different insecticide regimes (buprofezin followed by pyriproxyfen, pyriproxyfen followed by buprofezin, and a rotation of conventional materials), three action threshold levels for initiating insecticide treatments, and application by either air or ground equipment. Each treatment was replicated 3 times in 1.6 hectare plots.

A key component of these studies was examination of the effects of these management systems on the abundance and activity of native natural enemies of *Bemisia*. Weekly sweepnet samples were used to estimate the abundance of arthropod predators, and leaf samples (7th mainstem node) were used to estimate the abundance and activity of whitefly parasitoids. Predators will be subject to serological analyses to examine relative frequency of predation on *Bemisia* in relation to insecticide regime. Our goal is to assess the effect, if any, that IGRs and conventional insecticides have on predator feeding behavior under realistic field conditions. At present, predator samples are being processed. Approximately half of all leaf samples for parasitoids have been processed. Preliminary results indicate that *Eretmocerus* nr. *californicus* and *Encarsia meritoria* were present throughout the season, although the former species was dominate, comprising about 75% of all parasitoids collected. Application method and action threshold level appeared to have little effect on parasitoid abundance and activity. Rates of parasitism reached 75% in some plots and was higher on a number of sample dates throughout the season in plots sprayed with either buprofezin or pyriproxyfen in comparison with those treated with mixtures of conventional insecticides. Rates of parasitism generally increased over the season as *Bemisia* populations declined and averaged about 10% over the whole experimental area for the season. A severe storm in late July severely depressed populations of both host and parasitoids.

Investigator's Name(s): M. S. Palaniswami.

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January - December 1996.

Bemisia Tabaci Genn. and Its Natural Enemies

Bemisia tabaci Genn. has gained significant importance as a vector as well as a pest on many crops including tuber crops. Indiscriminate use of pesticides and resulting mortality of natural enemies of the whitefly have elevated the whitefly from a minor pest to pest of economic importance. Indigenous parasitoids, predators and pathogens are enumerated along with the bioecology of *B. tabaci*. Future lines of works on the identification of potential biotic agents for the whitefly management are discussed.

Investigator's Name(s): Charles H. Pickett[1], J. A. Goolsby[2], William L. Abel[3], and G. Boyd[1].

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: Fall 1995 - Fall 1996.

Colonization of Parasites for Biological Control of Silverleaf Whitefly in the San Joaquin Valley, California

The USDA-APHIS Biological Control Center at Mission, Texas has been actively importing, rearing and testing new species of silverleaf whitefly parasites for release against this pest over the last four years. Surveys by the California Department of Food & Agriculture's Biological Control Program have found only limited populations of three different species of aphelinids associated with silverleaf whitefly infestations in central California. In an effort to increase the diversity of natural enemies attacking this pest, CDFA and the USDA-APHIS PPQ reared and released 29 new populations/species of aphelinids over the last three years in central California. In 1994 and 1995 parasites were released in home gardens in the Bakersfield area of the southern San Joaquin Valley. These served as year round field insectaries or refuges, free of pesticides and untimely cultivation. Sites were selected that contained woody perennial plants susceptible to silverleaf whitefly (e.g. hibiscus, lantana) and had home vegetable gardens. Releases were made so that each site received species combinations that could be separated morphologically or through genetically unique DNA patterns. In 1994 a grand total of 99,500 parasite pupae were released representing six species/populations; in 1995 a grand total of 183,714 pupae were released representing 27 species/populations of aphelinids. In 1995 two of the six species/populations released in 1994 were recovered as late as August 1995 at one release site, both old world *Eretmocerus*. In 1996 exotic *Eretmocerus* have been recovered from five of 13 1994/1995 release sites.

In 1996 three different populations of *Eretmocerus* that performed well in laboratory and field tests were released into agricultural settings rather than homesites, as in 1995 (populations from Multan, Pakistan; Murcia, Spain; and United Arab Emirates). Releases were made in or near agricultural crops in order that parasites could overwinter on non-crop weedy vegetation. These included fields of cotton, citrus, small plantings of okra, and weedy areas near such crops. Release sites will be sampled next year for released parasites.

Investigator's Name(s): Charles H. Pickett[1], Kim A. Hoelmer[2], and William J. Roltsch[3].

Affiliation & Location: [1]Biological Control Program, CDFA, Sacramento, CA; [2]USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA; [3]Biological Control Program, CDFA, Brawley, CA.

Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: Fall 1995 - Fall 1996.

Systematics of *Delphastus* and Biological Control of Whiteflies

Delphastus spp. (Coleoptera: Coccinellidae) are important predators of whiteflies (Aleyrodidae) including species of *Bemisia*. Laboratory and greenhouse studies have demonstrated that *Delphastus* spp. consume large numbers of *Bemisia* eggs and nymphs while developing from larvae to adults and can play an important role in controlling *Bemisia* on infested poinsettias. These studies and others have used *Delphastus* from a stock culture originating in Florida and identified as "*pusillus*." Recently Robert Gordon published a new key to the species of *Delphastus* in the western Hemisphere (*Frustula entomol.* 1994). Based on a new set of characters developed during this revision, vouchers used in some of these studies have been renamed as *D. catalinae*. The species is found in South, Central and North America, as well as the Canary Islands and Hawaii. This may be an artificial distribution caused by the movement of cut flowers and fruit on which the beetles could be transported.

While using Gordon's key for species determinations, we learned that a population of *Delphastus* in Arizona previously treated as a synonym for *D. pusillus* is now considered a separate species, *D. sonoricus*. Therefore populations of *Delphastus* were collected in the Phoenix region in 1995 and imported into California in an effort to increase the number of specialized predators attacking *Bemisia* in Imperial Valley. *Delphastus sonoricus* was first collected by George Butler in the greater Phoenix area of Arizona and reported by Gordon (1994). The beetle was collected from homesites in Mesa, Arizona fall 1995 and released at several locations in Imperial Valley. About 100 adults were released at each of three homes in Brawley and a natural enemy refuge plot at the USDA-ARS Irrigated Desert Research Station. Beetles in the refuge have now survived for over a year and have been collected at one site in Brawley, about 1 mile north of the Research Station. The recovery of *D. sonoricus* is especially noteworthy since we released over thirty thousand individuals of *D. catalinae* (previously referred to as *D. pusillus*) in Brawley and El Centro in fall 1993, yet have not recovered any adults since that time.

Investigator's Name(s): William J. Roltsch[1] and John A. Goolsby[2].

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: November 1995 to September 1996.

Field Cage Evaluations on Non-Indigenous Parasitoids in Desert Crops

In conjunction with non-indigenous parasitoid evaluations conducted by Kim Hoelmer, USDA-APHIS, we have evaluated autoparasitic species/strains on broccoli, cantaloupe and cotton. These evaluations were conducted at the same field site and using similar methods described by Kim Hoelmer (see abstract) with several exceptions. Special efforts were made to ensure favorable sex ratios (1:5 male:female) during release. Also, when F1 pupae were observed, additional females were introduced during two consecutive weeks. This was done in order to de-synchronize the parasitoid generations within each cage to assure continual male and female production.

Morphologically indistinguishable autoparasitic *Encarsia transvena* [M93003 (Spain), M94041(Thailand) and M94047 (Malaysia)] were evaluated simultaneously in broccoli and cantaloupe. In each instance, M93003 produced the greatest number of F1 offspring. F2 production by M93003 in broccoli was weak, with densities declining from F1 counts. F2 production on cantaloupe yielded a modest increase of approximately 6 fold for M93003 and M94041.

Cotton tests in 1996 included M93003, *E. transvena* M95107 (Pakistan) and *Encarsia* sp. M92018 (strenua group, India). On cotton, M93003 gave a response similar to that on cantaloupe. Also, M93003 and M92018 yielded a modest F2 increase that was highly variable among cages. In contrast, M95107 produced numerous F1 in two cages and an extraordinary number in the third cage. F2 production of M95107 was very strong in all three cages. The test on cotton occurred during a very hot July and August period.

Crop	Accession #	F1 Mean Fecundity
Broccoli	M93003	12.9 [10.3-15.5]
Broccoli	M94041	4.1 [2.7-4.8]
Broccoli	M94047	6.1 [4.2-7.5]
Cantaloupe	M93003	17.6 [10.6-24.7]
Cantaloupe	M94041	14.8 [9.2-22.7]
Cantaloupe	M94047	1.6 [0.3-2.4]
Cotton	M93003	17.7 [9.0-40.3]
Cotton	M95107	78.5 [20.3-185.2]
Cotton	M92018	9.9 [6.9-8.1]

Investigator's Name(s): William Roltsch[1] and Greg Simmons[2].

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Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: March 1996 to November 1996.

Release and Establishment of Exotic Natural Enemies in Home Gardens and Agricultural Field Refuges in Imperial Valley, CA

Finding ideal habitat to establish exotic natural enemies is a challenge. Potential habitat is often unstable because many crops are short lived annuals and are commonly treated with insecticides. Furthermore, few ornamental or agricultural cultivars that are attractive to both whitefly and parasitoids do well during the extreme summer heat. This project represents a concerted effort to contact and work with avid home gardeners who grow garden plants nearly all year long and do not apply pesticides. Furthermore, refuge field plots composed of multiple plant species have been utilized for establishing exotic spp. as well. These plots (.5-1 acre) are located in or adjacent to commercial fields.

Based on parasitism records collected from field plots and home yards in past years, basil, eggplant, and roselle were selected to be provided to home gardeners to assure continuous habitat at the home sites. Basil and roselle were particularly useful throughout the summer and fall. Although whitefly numbers on roselle are typically low, parasitism rates are high and it grows very well in July and August, at a time when many plants don't grow well. Furthermore, roselle is a desirable plant for home gardeners because of its visual attractiveness and edibility of foliage. At field plot natural enemy refuge sites, basil, okra, eggplant, kenaf and roselle were selected for planting in 10 to 12 bed blocks at several locations in Imperial Co.

From April to November of 1996, parasitoids were released at 20 home sites and at 5 refuge field plots. Parasitoids were produced on hibiscus by CDFA in Sacramento, and on eggplant by USDA-APHIS in Imperial Co. Releases were made four or more times at each site. Parasitoids were delivered to each location as pupae on potted hibiscus plants or eggplant that were in turn transplanted and watered for several weeks. From 100,000 to over 1 million parasitoid pupae were released for each of five parasitoid species/strains. These include USDA accession numbers: M94056 *Encarsia* (>1 million), M93003 *Encarsia* (>100,000), M92014 *Eretmocerus* (>100,000), M95104 *Eretmocerus* (>100,000), and M95012 *Eretmocerus* (>2 million). Population densities were monitored on three occasions at each field plot in 1996 and will be monitored at each home site during the spring and late summer of 1997. One or more exotic *Eretmocerus* sp. reproduced readily at each field plot refuge.

Investigator's Name(s): A. L. Simmons[1], L. Williams III[1], T. J. Dennehy[1], L. Antilla[2], L. E. Jech[3], and S. Husman[3].

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Research and Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1995 - 1996.

Investigations of Two Insect Growth Regulators against Arizona Whitefly Populations

Insect growth regulators (IGRs) served a critical role in overcoming the whitefly resistance crisis that occurred in Arizona in 1995. With the granting of a section 18 exemption in 1996, an integrated resistance management strategy was implemented to sustain the efficacy of the IGRs by using them sparingly and in the context of IPM. Bioassay methods were adapted to test susceptibility of Arizona whitefly populations to the growth regulators buprofezin (Applaud®) and pyriproxyfen (Knack®). Susceptibility of six populations was estimated early in the 1996 season, prior to use of IGRs, and late season, after IGR treatments were applied to cotton.

All Arizona populations were more susceptible to Applaud and Knack than were Israeli whiteflies, based on published reports of Israeli findings. Significant differences were found between Arizona whitefly populations in susceptibility to Applaud and Knack during both the early and later season evaluations. Probit responses of the bulked data for all six populations early- and late-season were indistinguishable for response to Applaud but, significantly higher for late-season response to Knack. Field performance of both IGRs was excellent. Knack provided a minimum of 30 days of whitefly suppression, while Applaud provided at least 14 days suppression. The numbers of insecticide treatments applied for whiteflies was reduced greatly in 1996, relative to 1995.

Findings from the Netherlands and Israel have demonstrated the relatively rapid development of whitefly resistance to both Applaud and Knack. To sustain the impressive turn-around in whitefly control achieved with the IGRs we recommend that Arizona cotton growers continue to limit their use to once per season. Additionally, the Arizona whitefly resistance management program will strongly emphasize delaying use of pyrethroids, conservation of natural enemies, and appropriate use of monitoring and thresholds.

Investigator's Name(s): Alvin M. Simmons and D. Michael Jackson.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: August - November 1996.

Abundance of Native Whitefly Parasitoids Following Foliar Insecticide Treatments of Vegetables

Research was conducted to provide supporting information on work conducted in 1994 and 1995 on the impact of a foliar insecticide on abundance of native whitefly parasitoids in vegetables. Crops of cantaloupe, collard, and tomato were each established in three fields. Collard and tomato were transplanted after emergence of the cantaloupe. Half of each crop within each field was treated bi-weekly with foliar imidacloprid (Provado®) at 0.1 lbs ai/acre for a total of 5 treatments over the season. No other pesticide was used after the crops were planted. Yellow sticky cards were placed in each subplot. These were retrieved after one week and the number of captured adult *Bemisia argentifolii* and its parasitoids were counted in the laboratory. The majority of the captured parasitoids were *Eretmocerus* sp. (42%), *Encarsia nigricephala* (28%), and *Encarsia pergandiella* (27%). Only a small proportion of the parasitoids were *Encarsia strenua* and *Encarsia quaintancei*. The abundance of *B. argentifolii* and the parasitoids varied among fields. Across all fields and crops, ca. 65% of the parasitoids were captured in the untreated plots compared with the imidacloprid treated plots. This persistence of parasitoids in the treated crops is consistent with what we found in 1994 and 1995 using chlorpyrifos (Lorsban®) and Provado®, respectively. Approximately half of the parasitoids collected were from collard. However, we note that over the last two sample weeks, cantaloupe plant quality was poor (many dead plants) because of fungal diseases following a wet period. Conversely, high numbers of parasitoids and whiteflies were collected in collard over the final two sample periods.

Investigator's Name(s): Gregory S. Simmons[1], Kim Hoelmer[2], Robert Staten[2], Theodore Boratynski[1], and Eric Natwick[3].

Affiliations & Locations: USDA-APHIS-PPQ, Western Region[1] and Phoenix Plant Methods Center[2], Brawley, CA; and University of California Cooperative Extension[3], Holtville,CA.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January 1996 to December 1996.

Seasonal Inoculative Biological Control with Parasitoids of *Bemisia* Infesting Cantaloupe in the Imperial Valley of California: A Report on Three Years of Investigations

The primary goal of this project was to increase biological control of the silverleaf whitefly (SLW) in spring melons by rearing and releasing several species of SLW parasites. Native parasites of SLW (*Eretmocerus* sp. & *Encarsia* spp.) are not effective against SLW on spring melons and levels of parasitism are generally low on these crops in the Imperial Valley of California. It is in the spring melon crop where SLW populations first start to rapidly increase leading to high regional populations that go on to infest cotton and alfalfa after the melon harvest. If a more effective parasite against SLW infesting spring melons was introduced in these agroecosystems, it should result in lower whitefly populations on successive summer crops and lead to higher populations of parasites at the beginning of the next planting.

Three years of field investigations of biological control of SLW infesting spring cantaloupe have demonstrated that parasitism can be increased and whitefly populations suppressed by making open field inoculative releases of *Eretmocerus* spp. in 1/2-acre release plots of non-treated melons contained within larger commercial fields. Releases of exotic *Eretmocerus* species M92019, M92014 and M95012, collected from India, Spain, and Pakistan respectively, have all proven to be about equal in performance and appear to be more effective than releases of the native *Eretmocerus* sp. Mean rates of parasitism achieved have ranged from 25-43%. These levels of parasitism were significantly higher than the 7-11% parasitism by naturally occurring native *Eretmocerus* observed in no-release plots. Parasitism in individual plots reached levels of parasitism as high as 85% indicating that high levels of parasitism are possible. Whitefly levels were reduced by as much as 59% in release plots and were significantly lower than whitefly levels in the no-release control plots. The number of parasites needed to achieve these levels of parasitism is estimated to be between 20,000 to 50,000 females per acre. It is unclear why higher levels of parasitism were not achieved; large numbers of emigrating whitefly from the surrounding field may have overwhelmed the ability of the parasites to provide adequate control.

Releases of *Eretmocerus* spp. parasites into Admire™ (imidacloprid) treated melons also resulted in increased parasitism and reduced SLW levels. Levels of parasitism similar to those observed in the untreated trials have been observed, suggesting that Admire use and parasite release are compatible. In 1996, an experiment was conducted to determine if parasite release in Admire treated fields could replace late season use of pyrethroids and other broad spectrum pesticides that growers often need to apply to control late season whitefly that develop after the Admire application is no longer effective. In the parasite release plus Admire treatments, levels of parasitism of 25% were observed which was significantly higher than that in no-release plots and whitefly levels were similar to those in the pyrethroid (bifenthrin) plus Admire treated plots suggesting that it is possible to replace pyrethroid application with parasite release. Reduced applications of pyrethroids could allow increased biological control of SLW by conserving indigenous natural enemies or by allowing the use of seasonal inoculations of parasites. If Admire treatment was combined with low release rates of parasites, further applications of pesticides may be unnecessary providing savings to the grower. Reduced applications of pesticides would also conserve naturally occurring enemies of other pests such as leaf-miner and aphids. Furthermore, increased biological control of SLW in Admire treated spring melons could delay the development of resistance to Admire, as whiteflies that escaped treatment could potentially represent resistant individuals. Similarly, reducing the need for applications of other insecticides such as bifenthrin could delay the development of SLW resistance to other classes of insecticides, thus preserving the utility of these important control tools. Lastly, replacing late season pesticide applications with parasite release would be helpful to growers by eliminating the need to observe cumbersome worker safety regulations and lengthy reentry intervals associated with restricted use pesticide applications.

Investigator's Name(s): S. Sivasupramaniam, T. J. Dennehy, and L. Williams III.

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Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1995 - 1996.

Management of Pyrethroid-Resistant Whiteflies in Arizona Cotton: Selection, Cross-Resistance, and Dynamics

In 1995, silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, resistance to the widely-used mixture of Danitrol® (fenpropathrin) + Orthene® (acephate) was shown to be severe and widespread in Central Arizona cotton. Thereafter, laboratory experiments were undertaken to identify the other major insecticides that were affected by this resistance. Large numbers of whiteflies were collected in November of 1995 from Maricopa (highly resistant) and Yuma (relatively susceptible) County locations in Arizona. A composite colony was establishing by combining Yuma and Maricopa whiteflies in a 4:1 ratio. After six generations of adult selection of this population, appreciable shifts in the concentration responses for pyrethroid, organophosphate, and carbamate insecticides were witnessed, indicating heritable variation for resistance in the source populations. From this we obtained definitive proof that resistance to Danitol + Orthene confers cross-resistance to Asana® (esfenvalerate), Capture® (bifenthrin), Danitol, Decis® (deltamethrin), Decis + Orthene, and Karate® (lambda-cyhalothrin). Additionally, selection with Danitol + Orthene resulted in statistically significant reductions in susceptibility to Curacron® (profenofos), Lannate® (methomyl), Monitor® (methamidaphos), and Ovasyn® (amitraz).

Studies were performed to assess tolerance of Maricopa (pyrethroid-resistant) and Yuma (relatively susceptible) populations to a diversity of conventional insecticides currently registered for use in Arizona cotton, with the intention of finding compounds that showed promise for overcoming pyrethroid resistance. Of the materials evaluated, Curacron, Lannate, Lorsban® (chlorpyrifos), Ovasyn, Supracide® (methidathion), and Vydate® (oxamyl) were most promising. To determine to what degree pyrethroid resistance in cotton influenced resistance in winter vegetables and melons, and vice versa, whitefly populations were collected from a succession of these crops in Western and Central Arizona regions. In most instances, the whiteflies in Western Arizona were significantly more susceptible to Danitol + Orthene than those in Central Arizona. Significant decreases were found in susceptibility to Danitol + Orthene during the 1996 season at three of the four locations in which multiple crops were monitored. This emphasizes that pyrethroid resistance levels can be increased in whitefly populations from any of the cotton, melons, or other winter vegetable crops evaluated. Therefore, management of pyrethroid resistance in Arizona cotton will require harmonizing resistance management efforts and specifically limiting pyrethroid use in the entire crop complex.

Investigator's Name(s): Michael T. Smith[1], Miriam Allred[2], Daniel Fieselman[3], Matthew Ciomperlik[4], Blake Layton[5], James Jarratt[5], Pat Harris[6], Andy Milling[6], and Rick Snyder[7].

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Research & Implementation: Section D: Biological Control.

Dates Covered by the Report: 1995 - 96.

Survey and Identification of the Whitefly and Associated Parasitoid Species in Mississippi

The silverleaf whitefly, formerly the sweetpotato whitefly, is a serious pest on cotton, vegetables, ornamentals and many other agronomic crops throughout a large area of the United States, including both field and glasshouse agroecosystems. However, its importance in Mississippi is not known. Therefore, in concert with parasitoid evaluations, and as a prerequisite to subsequent potential releases and evaluation of natural enemies, a survey of the whitefly and associated parasitoid species in Mississippi was conducted in 1995-96. The objectives of this research were to survey as wide a geographic area of the state, including the four distinct agroecosystems (delta, hills, coastal plains, black prairie), as wide a host plant range, and as wide a variety of agronomic/management systems as possible. Leaves from whitefly-infested plants were collected weekly or as whitefly populations were observed. Whitefly specimens were observed under a dissecting microscope, and pupal case characteristics were used to identify and classify individuals to species. In cases where specimens were keyed to *B. tabaci*, several recently identified morphological features were used in part to distinguish *B. argentifolii* and *B. tabaci*. However, since diagnostic pupal characters have not been entirely satisfactory, live adults were transferred to squash, allowed to lay eggs, and the subsequent nymphs allowed to feed and develop. Expression of the phytotoxic disorder of silverleaf was used to confirm the identification of *B. argentifolii*. Whitefly-infested leaves were then transferred to rearing boxes and the parasitoids allowed to emerge. Parasitoids were tentatively identified using two recently published keys.

In the 1995 survey, a total of 175 samples were collected, 98.3% of which were infested with whiteflies. Four whitefly species were identified: *Trialeurodes abutilonea, Trialeurodes vaporariorum*, *Bemisia tabaci* and *Bemisia argentifolii*, which comprised 29.6%, 9.9%, 18.6% and 17.4%, respectively, of the infested samples. The remaining samples contained either *Bemisia* spp. (9.9%), or unidentified whitefly species (14.5%). Whiteflies were found infesting cotton, soybeans, vegetables (17 species), and ornamentals (16 species), comprising 18.3%, 14.3%, 29.6%, and 37.2%, respectively, of the infested samples, across 19 counties. Parasitoids were collected from 48.6% of the infested samples, and tentatively identified as (% of parasitized whitefly samples): *Amitus* sp. (0.9%), *Encarsia* sp. (33.9%), including *Encarsia americana*, *Encarsia cubensis*, *Encarsia meritoria*, *Encarsia nigricephala, Encarsia pergandiella, Encarsia quaintancei*, *Eretmocerus* sp. (47.8%), *Metaphycus* sp. (1.7%), *Signiphora* sp. (4.4%), and unidentified species (13.0%).

In 1996, a total of 283 samples were collected, 95.4% of which were infested with whiteflies. Four whitefly species were again identified: *T. abutilonea*, *T. vaporariorum*, *B. tabaci* and *B. argentifolii*, which comprised 45.2%, 13.0%, 4.4% and 8.5%, respectively, of the infested samples. The remaining samples contained either *Bemisia* spp. (0.7%), or unidentified whitefly species (20.7%). Whiteflies were found infesting cotton, soybean, 6 vegetable species, 26 field ornamental species, and 19 greenhouse ornamental species, comprising 44.2%, 11.8%, 9.3%, 18.5% and 18.5%, respectively, of the infested samples, across 26 counties. Parasitoids were collected from 10.4% of the infested samples, and tentatively identified as (% of parasitized whitefly samples): *Amitus* sp. (2.8%), *Encarsia* sp. (33.3%), including *E. americana*, *E. meritoria*, *E. nigricephala, E. pergandiella, E. quaintancei*, *Eretmocerus* sp. (41.7%), *Metaphycus* sp. (2.8%), *Signiphora* sp. (2.8%), and unidentified species (13.9%).

This survey will be continued in 1997, with isoelectric focusing being incorporated into the whitefly identification protocol. Efforts will also be made to formulate recommendations whose aim is to minimize the probability that *B. argentifolii* will become a severe pest in Mississippi agricultural systems.

Investigator's Name(s): Don C. Vacek, Raul A. Ruiz, and Lloyd E. Wendel.

Affiliations & Locations: USDA-APHIS-PPQ, Mission Biological Control Center, Mission, TX.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: 1993 - 96.

RAPD-PCR Identification of Natural Enemies of SPWF

Genetic fingerprinting with randomly amplified polymorphic DNA (RAPD) provides a rapid and reliable method for insuring quality control of mass-reared biological control agents and identifying undescribed populations of potential biological control agents. The integration of molecular genetic techniques into quarantine importation and culture of exotic natural enemies has enhanced the implementation of biological control of *Bemisia tabaci,* biotype B (SPWF). The Mission Biological Control Center (MBCC) serves as the primary quarantine for USDA in the importation of natural enemies of SPWF. Voucher specimens of the natural enemies imported and cultured in the quarantine laboratory are provided to both systematists and the MBCC Genetics Diagnostics Laboratory. While systematic determinations are in progress, specimens are rapidly and reliably identified with genetic fingerprints.

A total of 53 *Encarsia* populations from 18 countries (Africa, Argentina, Brazil, Cyprus, Dominican Republic, Egypt, Ethiopia, Greece, India, Israel, Italy, Malaysia, Nepal, Philippines, Spain, Taiwan, Thailand, and U.S.A.) were divided into 19 RAPD pattern groups which generally followed species designations where available. The *Encarsia* patterns were distributed uniquely as follows: U.S.A. (EN 9, 12), U.S.A. and Italy (EN 8), India (EN 1), Southeast Asia (EN 3, 4, 6, 11), Dominican Republic (EN 18), Mediterranean (EN 7, 10, 13, 14), Africa (EN- 5, 19) and South America (EN 15, 16, 17). Two patterns were widely distributed (EN 2, 5). The *Encarsia* populations will most likely be classified as the following species: *E. formosa*, *E. transvena*, *E.* nr. *strenua*, *E. pergandiella*, *E.* nr. *pergandiella,* and *Encarsia* sp.

A total of 43 *Eretmocerus* populations (representing *Eretmocerus* spp. and several undescribed species) from 11 countries (Egypt, Ethiopia, India, Israel, Italy, Pakistan, Spain, Taiwan, Thailand, United Arab Emirate, and U.S.A.) were divided into 12 RAPD pattern groups. The *Eretmocerus* patterns were distributed uniquely as follows: India (ERET 2), United Arab Emirates and Ethiopia (ERET 12), Pakistan (ERET 10), U.S.A. (ERET 4, 5, 6, 7), and Southeast Asia (ERET 3, 8, 9, 11). One pattern was widespread (ERET 1). Genetic fingerprinting with RAPD complements systematic determinations and is an effective way to identify insects for delivery of a biological control program.

Investigator's Name(s): Fernando E. Vega[1], Mark A. Jackson[2], and Michael R. McGuire[1].

Affiliation & Location: USDA, ARS, National Center for Agricultural Utilization Research, [1]Bioactive Agents Research Unit and [2]Fermentation Biochemistry Research Unit, 1815 N. University St., Peoria, IL 61604.

Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: June - November 1996.

Germination of Conidia and Blastospores of the Fungal Entomopathogen *Paecilomyces fumosoroseus* on Silverleaf Whiteflies

Paecilomyces fumosoroseus (Deuteromycotina: Hyphomycetes) is a fungal entomopathogen with a broad host range. The fungus produces blastospores in liquid media and conidia in solid media. We used scanning electron microscopy to assess germination rate of conidia and blastospores on the cuticle of silverleaf whiteflies (*Bemisia argentifolii* Bellows & Perring) at different periods of time after spraying.

P. fumosoroseus was grown in liquid medium for 4 days at 28°C and 300 rpm, and a blastospore suspension with a concentration of $1.2x10^9$ blastospores/ml was prepared. For conidia, Petri plates containing Sabouraud dextrose maltose agar were inoculated with *P. fumosoroseus*, and after harvesting the conidia, a suspension of $4.1x10^7$ conidia/ml was prepared. Silverleaf whiteflies were reared on cotton seedlings at 25°C, 60 RH, and a 12:12 (L:D) photoperiod. Leaves with nymphal stages were placed under a Burkard Computer Controlled Spraying Apparatus designed to spray four leaves in one run. Controls were sprayed with sterile distilled water. Leaves sprayed with conidial suspensions were run three consecutive times to guarantee a high number of conidia landing on the insects. Immediately after spraying each leaf was transferred to a Petri plate containing 2% agar, and sealed with Parafilm. The plate was inverted so that the abaxial side of the leaf faced down, with the adaxial side touching the agar. Plates were stored in the dark at 24°C, and leaf sections containing nymphs were collected immediately after spraying, and 2, 4, 8, and 24 hours later. The leaf sections were placed inside Petri plates and stored at -74°C, until all samples had been collected. At this time, leaf sections were freeze dried. Gold-palladium was used to fix the samples and a scanning electron microscope was used to assess germination. Fifty conidia or blastospores on each of three nymphs per sampling time were assessed for germination, which was deemed positive when a germ tube was seen projecting from the spore.

Blastospores germinated at a faster rate than conidia. Immediately after spraying, 3% of the blastospores were already germinating, indicating that the conditions in the liquid medium were sufficient to induce germ tube formation. The percent germination for blastospores was significantly higher than for conidia 2, 4, and 8 hours after spraying, but not at 24 hours. The percent germination of blastospores increased to 15% at 2 hours, 37% at 4 hours, 43% at 8, and 96% at 24 hours. In contrast, the first indication of conidia germination was at 8 hours, when 31% were germinated, followed by 99% at 24 hours. Fast spore germination presents several advantages, among these, increased pathogenicity, as has been shown for other insects. Fast germination should also reduce the importance of environmental factors; once the spore has germinated dependence on relative humidity, for example, is reduced. The longer the spore remains ungerminated, the more likely it could be affected by chemical components on the cuticle (e.g., antibiosis) and desiccation. Spores that germinate fast are more likely to infect immature stages of the insect before ecdysis, thereby, reducing the chances of spore loss through ecdysis. The use of blastospores as the active ingredient in a formulation should prove to be advantageous over conidia if a faster germination is maintained in the formulated material.

Investigator's Name(s): Livy Williams III, Timothy J. Dennehy, and John C. Palumbo.

Affiliation & Location: Extension Arthropod Resistance Management Laboratory, Department of Entomology, University of Arizona.

Research & Implementation Area: Section D: Biological Control.

Dates Covered by the Report: 1995 - 1996.

Defining the Risk of Resistance to Imidacloprid in Arizona Populations of Whitefly

A resistance management program for imidacloprid was initiated in Arizona in 1995, the ultimate goal of which is to sustain the efficacy of this insecticide against *Bemisia*. The current paper reviews our progress toward defining the risk of resistance to imidacloprid in Arizona whiteflies. Bioassay methods for adult whitefly consisted of a 1-day hydroponic uptake by cotton seedlings, followed by a 2-day exposure period. Results from statewide monitoring indicate that whitefly populations throughout Arizona are susceptible to imidacloprid; however, slight increases in resistant whiteflies were observed in 1996, as compared to 1995. Thus far, selection studies with various Arizona whitefly populations have not led to reduced susceptibility to imidacloprid. In a study exploring the influences of different cropping systems on imidacloprid use, we found no major differences in susceptibility to imidacloprid between populations of whiteflies in central and southwestern Arizona. Continued effective management of Arizona whitefly will, in part, hinge on our ability to more effectively integrate our knowledge of whitefly biology with resistance management strategies.

Investigators Names: S. Wraight[1], C. Bradley[2], S. Jaronski[2], S. Galaini-Wraight[2], J. Garza[1], F. De La Garza[3], O. Munguia[2], M. De Anda[1], A. Rosales[1], and M. Becerra[2].

Affiliations & Locations: [1] USDA-ARS Subtropical Agricultural Research Laboratory (SARL), Weslaco, TX, [2] Mycotech Corporation, Butte, MT; [3] Texas A&M University, Weslaco, TX.

Research and Implementation Area: Section D: Biological Control.

Dates covered by the report: January 1996 - December 1996.

Efficacy of Mycotrol® (*Beauveria bassiana* Strain GHA) Against Silverleaf Whitefly on Cucurbit Field Crops in The Lower Rio Grande Valley of Texas

The collaboration between Mycotech Corporation and SARL aimed at developing insect pathogenic fungi for biological control of whiteflies continued through 1996. The *B. bassiana*-based mycoinsecticide codeveloped by Mycotech and SARL trade named Mycotrol WP (U.S. EPA Registration No. 65626-7) was evaluated in a number of commercial demonstration trials.

Treatment areas, usually within larger fields, ranged between one and five acres. Applications of Mycotrol were made weekly at a rate of 0.5 lb/ac (1×10^{13} conidia/ac) with a tractor-driven, high-pressure (400 psi) hydraulic sprayer with nozzles mounted on flexible drop tubes. Two to four applications in cucumbers and six to seven applications in cantaloupe melons and zucchini squash, initiated at the time of first generation egg hatch, reduced late-instar larval populations of *B. argentifolii* by 70-80% compared to untreated and spray carrier controls. In these trials, yields from Mycotrol treatments were statistically equivalent to treatments with chemical insecticides. Poor results were obtained in only one full-season trial in spring-planted melons. In this test, the spray program was delayed due to irrigation and initiated only after the appearance of late instars. Spray efficiency was also reduced on several occasions by windy conditions. Only 45% control of the first generation was achieved, and yields were reduced by approx. 40% compared to imidacloprid treatments. Two trials in which Mycotrol was applied to cantaloupe melons to control late-season larval populations developing after depletion of imidacloprid were also unsuccessful. Sampling indicated that the lack of control in these cases resulted from poor spray coverage of the leaf undersides in the mature, dense melon canopy.

Field studies confirmed that thorough coverage of the lower surfaces of crop foliage is one of the most important elements of successful control. Recumbent plants represent a particularly difficult spray target. Studies in cucurbits indicate that a number of spray parameters, including hydraulic pressure, spray volume, nozzle spacing, and proximity of the nozzles to the crop canopy can be manipulated to substantially increase spray efficiency. In short-cycle crops like cucumbers, effective spray coverage is usually maintainable for sufficient time to protect the crop. However, in long-cycle crops such as melons, effective coverage is difficult to achieve and maintain late in the season after the canopy has reached its maximum size and density.

Our studies have revealed that whitefly adults are more resistant to fungus infection than larvae, and large populations of adults migrating into young crops are not controllable with *B. bassiana* alone. Fortunately, this pathogen is compatible with most synthetic chemical adulticides. We have recently been successful in employing an initial application of endosulfan to reduce migrating adult populations followed by weekly applications of Mycotrol to control larvae. Other integrated uses are also under investigation. In drip-irrigated cucurbits, we are studying the potential of making foliar applications of fungus prior to application of systemic insecticides like imidacloprid to the soil through the drip lines. This approach could extend the efficacy of these chemicals into the latter half of the season when control with foliar sprays of other agents is difficult to achieve.

* Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

TABLE D. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section D: Biological Control

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
D.1 Determine effects of indigenous natural enemies on regulating SLWF populations.	Year 5: Examine species and methods for exploiting selected natural enemies in crop systems.	X		Exploitation of native natural enemies is feasible and shown to be effective only in a few agricultural or urban systems.
D.2 Develop methods for enhancing habitats with refuge plantings to conserve natural enemies.	Year 5: Implement and evaluate large scale conservation management systems.		X	Although new plants highly suitable for refuge plantings have been identified, large scale implementation has not been examined yet. A new banker plant method using vegetable transplants is being testing in TX.
D.3 Identify new natural enemies in areas of SLWF origin; foreign exploration, importation and release.	Year 5: Determine adaptation of introductions and effects on SLWF populations.	X		Rearing and releases of exotic natural enemies has really taken off. Several exotic parasitoid or predator species have been established in CA, AZ, TX and FL and seem to have an impact on SLWF populations in selected systems.
D.4 Determine natural enemy host selection processes and mechanisms.	Year 5: Implement methodology developed into SLWF management systems.		X	We have a reasonable understanding of host selection in several predators and parasitoids. Implementation of this knowledge needs to be considered.
D.5 Inoculate/augment parasite and predator populations through propagation and release.	Year 5: Conduct areawide suppression trials and continue developing the mass propagation, distribution, storage and release technology.	X		Large scale field trials employing augmentation of parasitoids show promising results in CA and TX. Augmentative biological control using the native *Eretmocerus* (AZ) is effective against whiteflies in the greenhouse.
D.6 Determine effects of pathogens on regulating SLWF populations.	Year 5: Expand field evaluations and begin technology transfer.	X		Major progress has been made in product development and application technology by the commercial companies. Field testing is continuing at full force.
D.7 Evaluate compatibility of pesticides with SLWF natural enemies.	Year 5: Evaluate potential in large scale field trials.	X		Large scale field trials have demonstrated the effects of several pesticides, including insect growth regulators, on populations of natural enemies.
D.8 Systematics of predators, parasites and pathogens.	Year 5: Conduct molecular, biochemical, or other studies on target taxa.	X		An identification key of the North American *Eretmocerus* spp. has been published. Molecular classification of both *Eretmocerus* and *Encarsia* is finished. The classification of some predators and the pathogens is incomplete.

Investigator's Name (s): Allen C. Cohen, Tom Freeman, C. C. Chu, T. J. Henneberry, James Buckner, Dennis Nelson, and Pat Vail.

Affiliation & Location: Western Cotton Research Laboratory, USDA, ARS, 4135 E. Broadway Road, Phoenix, AZ 85040.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: March 1996 through December 1996.

Characteristics of Leaves of Cotton Varieties in Relation to Whitefly Feeding Biology

Seventeen cotton varieties were analyzed for characteristics related to whitefly feeding. Leaves were analyzed from plants sown at the UC Desert Research & Extension Center. The varieties analyzed wereDP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 9050, DPX 9057, NuCOTN 33b, CB 1135 and CB 1233 fro the US; and CS 50, Siokra L23 V-15, Siokra 1/649, 87031-126 and 89013-114 from Australia. Measurements were made of leaf thickness, distance from lower leaf surface (abaxial surface) to the nearest point on minor vascular bundles, number of minor vascular bundles per unit of leaf surface, thickness of epidermal cells and number of gossypol glands per unit of leaf surface. The differences between these characteristics are discussed in terms of potential resistance to whiteflies in light of what is know of the geometry of whitefly feeding.

Investigator's Name(s): Charles G. Cook.

Affiliation & Location: USDA-ARS, Subtropical Agricultural Research Laboratory, Weslaco, TX.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: 1994 - 1996.

Mechanisms of Resistance to the Silverleaf Whitefly and its Interaction with the Reniform Nematode: Applications to Cotton Breeding

Since the early 1990s, the silverleaf whitefly has become an increasingly important insect pest of cotton in the Lower Rio Grande Valley of Texas. Several elite cotton germplasm lines developed and released by the USDA-ARS, Subtropical Agricultural Research Laboratory (SARL) in Weslaco, Texas possess traits that confer host plant resistance to the silverleaf whitefly. These traits include the glabrous and/or smooth-leaf characteristic and earliness in maturity. For two consecutive years, 1995-1996, the first bale of cotton harvested in the United States has been Texas 121, which is a glabrous, very early maturing variety. The Texas 121 variety is a mass selection of C21S781-2, a germplasm line developed by the USDA-ARS and jointly released with the Texas Agricultural Experiment Station and Rio Farms, Inc. This variety has also shown outstanding potential in Guatemala and Nicaragua and will occupy a large percentage of their production in 1997. In preliminary field evaluations in Guatemala, Texas 121 has produced greater yields and shown less susceptibility to whitefly transmitted viruses than the Delta and Acala-type cottons that have been grown in the past. For the third consecutive year, a glabrous or smooth-leafed germplasm derived from the USDA-ARS, SARL program has produced the highest yields in the Texas Agricultural Extension Service Lower Rio Grande Valley Variety Test conducted by J. Norman. The top yielding entry in 1996, C118-2-93, had 0.54 leaf trichomes/cm^2, compared to 0.79, 1.29, 4.66, 18.18, 19.93, and 87.8 leaf trichomes/cm^2 for Deltapine 5409, Deltapine 51, Stoneville 495, Stoneville 132, Suregrow 125, and Stoneville 474, respectively. C118-2-93 and several other elite lines will be tested for resistance to the whitefly-transmitted crumple leaf virus in 1997.

Two-year results from a 3-year study to determine the singular and combined effects of the silverleaf whitefly and reniform nematode on cotton have shown very consistent results. When comparing yields of the imidacloprid-treated plots to the whitefly-infested plots, average lint yield was reduced 22% by whiteflies and 30% by reniform nematodes. Based on sequential harvests, the greatest yield losses in the whitefly plots were observed in the later harvests, indicating that whitefly damage increased as the season progressed and that managing for an early crop should have a significant impact on reducing damage. There was some indication of a silverleaf whitefly x reniform nematode interaction. Micronaire value was reduced by 0.5 units in the whitefly-infested plots, indicating the potential effects of whiteflies on fiber maturity. Of interest, the adult whitefly populations tended to be higher in the plots where reniform nematodes were controlled and plants under less stress. This finding was not expected and additional studies are needed to confirm this.

Investigator's Name(s): Luko Hilje, Douglas Cubillo, and Guido Sanabria.

Affiliation & Location: Plant Protection Unit, CATIE, Turrialba, Costa Rica.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: January-November 1996.

Delay of Geminivirus Dissemination in Tomato Fields by Interfering with *Bemisia tabaci* Adults

In Costa Rica, fresh-market tomatoes are severely affected by whitefly-borne geminiviruses. Minimum vector densities (as low as one adult per plant, on average), commonly cause up to 100% infection in the field. *B. tabaci* biotype C (*sensu* Dr. Judith K. Brown) does not breed on tomatoes, adults being the important stage towards which control measures should be focused.

The severity of the tomato yellow mosaic disease is higher when plants become infected during their critical period of susceptibility to viral infection (the first 60 days after sowing), sometimes causing total yield losses. Thus, a two-phase preventative management scheme has been proposed for small farmers, to delay geminivirus dissemination in tomato fields by interfering with the vector. During the first phase (up to 30 days after sowing), seedbeds are protected by fine nets. In the second phase (the first 30 days after transplanting), vector management is based on the use of soil covers and chemical repellents.

Production of virus-free seedlings has been possible using several types of containers (Tray Masters No. 51 tray, and medium and large home-made newspaper cups), placed inside small tunnels covered with fine nets (IN24, IN32, IN50; Toldenet Ltd., Arkansas). These systems provided 30 day-old, virus-free and high agronomic-quality seedlings (heights, weight, root length, and stem thickness). Seedlings grown in large newspaper cups were superior in quality; in addition, this technique was the least expensive alternative for growers. The use of newspaper cups combined with IN50 net protection would allow to produce enough seedlings for a hectare, at a cost of $453. Conversely, maintenance costs during the first month of a directly sown tomato field would cost approximately $1200/ha. Moreover, the net can be reutilized several times, with the corresponding savings.

Soil covers tested included both inert materials (silver and green plastics) and a living mulch ("cinquillo", *Drymaria cordata*), compared with a control treatment (bare soil) in farmers' fields. The silver plastic and *D. cordata* covers were superior to both the green plastic and control treatments in reducing adult abundance and delaying virus dissemination. Yields were 50.5, 24.9, 38.3, and 32.6 t/ha, respectively; the "cinquillo" was severely affected by late blight (Phytophthora infestans). Net benefit was highest in plots covered with silver plastic ($19,078/ha) and lowest in the "cinquillo" ($8,273/ha) plots.

Repellency tests involved plant extracts, biorationals, and synthetic insecticides. None of 19 plant extracts tested repelled *B. tabaci* adults. However, the following ones caused adult mortality levels higher than 85%: American pennyroyal, *Hedeoma* aff. *pulegioides* (96%); lemongrass, *Cymbopogon citratus* (95%); cocoa-shade, *Gliricidia sepium* (95%); common rue, *Ruta gaveolens* (94%); marigold, *Tagetes jalisciensis* (92%); "chilemuelo", *Drymis granatensis* (91%); bitter gourd, *Momordica charantia* (88%); jack bean, *Canavalia ensiformis* (87%); and eucalypt, *Eucalyptus degluta* (87%). Neither biorationals, such as neem derivatives (Azatin, Margosan-O, Nim 20, Nim 25, Nim 80, Nim-oil, and seed crude extracts), Garlic Barrier, Kilol, Repcit, Detur, M-Pede, Virol, ISK 45L, and Zohar, nor insecticides applied at sublethal doses (endosulfan, bifenthrin, fenpropathrin, and imidacloprid) caused repellency. A mineral oil (Volck 100 Neutral) showed some repellency activity.

Investigator's Name(s): K. A. Hoelmer[1], W. J. Roltsch[2] & C. C. Chu[3].

Affiliation & Location: USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA[1]; CDFA, Biological Control Program, Brawley CA[2], and USDA-ARS, Western Cotton Research Lab, Brawley, CA[3].

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: August to December 1996.

Comparison of the Selectivity of Whitefly Traps for Parasitoids of Silverleaf Whiteflies

Yellow sticky card traps for whiteflies are widely used for monitoring adult activity and sometimes for control of whitefly populations in field and greenhouse crops. Disadvantages of these traps include the tendency of the trap's adhesive to become clogged with non-target insects and dust, the inability to reuse the trap and the messiness of the glue. A new type of glueless, inexpensive and reusable dome-shaped cup trap was recently developed by C. C. Chu and T. J. Henneberry and evaluated for its ability to trap whitefly adults. We tested the new "C. C." trap, standard yellow sticky card traps and clear sticky cards as controls in cotton at the USDA Irrigated Desert Research Station at Brawley in August 1996 to compare the attractiveness of three traps to whitefly parasitoids (*Eretmocerus* species). In replicated trials, the new cup traps, 7.5 x 12.5 cm yellow sticky traps and 7.5 x 12.5 cm clear, colorless plastic panels coated with Tanglefoot were placed at canopy level (ca. 1 m height). The clear and yellow sticky traps were oriented horizontally with the sticky surface facing downwards.

The new traps caught an average of 264 adult whiteflies during 24 h test periods compared to 520 adult whiteflies on yellow sticky traps. The clear plastic sticky cards trapped only 37 whiteflies per card during the same period. The new cup traps caught an average of only 0.3 *Eretmocerus* per cup over a 24 h period compared with 25.6 adult *Eretmocerus* trapped by yellow sticky cards. Clear plastic sticky cards trapped an average of only 1.1 parasitoids per card, suggesting that adult *Eretmocerus* are actively attracted to the yellow sticky cards because of their color and become trapped in the glue. The proportion of adult female *Eretmocerus* trapped on sticky cards was 39% from the yellow and 42% from the colorless traps. A few parasitoids in the genus *Encarsia* were also trapped on the sticky cards but their numbers were very low: 0.1 adult per card or less. *Encarsia* was much less abundant in the cotton than *Eretmocerus;* consequently few were trapped.

Other insects were also trapped by each type of trap. The cup traps caught the fewest of other kinds of arthropods: on average less than one individual of any type per trap in each 24 h period. Very few beneficial insects were caught; these include several bee species and a few predators such as *Geocoris*, several spiders and reduviids. A few individual thrips and flies were also caught. Yellow sticky traps caught the greatest number of other arthropods; these included thrips, flies, leaf perforator moths, small beetles and other parasitic wasps. Clear sticky traps caught a similar mixture of species but in lower numbers.

These results demonstrate that the new "C.C." cup traps are highly selective for whitefly while preserving parasitoid populations. Since yellow sticky traps are widely used for whitefly monitoring and management, the new traps should be especially useful in greenhouses where traps are frequently used in conjunction with releases of parasitoids.

Investigator's Name(s): D. Michael Jackson, W. A. van Giessen, and M. W. Farnham.

Affiliation & Location: USDA-ARS, U.S. Vegetable Laboratory, Charleston, SC.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: 1996.

Is Breeding for Resistance to Silverleaf Whitefly a Viable Pest Management Approach?

Over the last five years there has been less research effort on plant resistance to insects (PRI) than on most other research areas for management of the silverleaf whitefly. In fact, PRI papers have been only 5.4% of the total number of abstracts published in the 5-year annual progress reviews on silverleaf whitefly for 1993-1996. Despite this, there are many advantages PRI technology could provide, including fewer pesticide residue problems and enhanced consumer acceptance, reduced negative environmental effects, and compatibility with other pest management options such as biological control. However, there is a perception by some researchers that because the silverleaf whitefly is highly adaptable, breeding for resistance is not a useful management strategy. They fear that resistance will break down under high selection pressures and the insect will adapt to a previously resistant host. However, the problem of whiteflies adapting to a control procedure is not restricted to PRI. Even though whitefly resistance to insecticides is well documented, these problems can be managed, and insecticides are an integral part of integrated pest management (IPM) programs. We contend that given sufficient information about the agricultural system involved, whitefly-resistant cultivars also can be used effectively for IPM programs, and with careful consideration these genetic resources can be preserved. Use of proven techniques, such as breeding for polygenic resistance, pyramiding of genes, use of mixed seed lots, and sequential releases of resistant cultivars with different mechanisms of resistance, can help delay or prevent the development of biotypes. We should ask ourselves how durable a resistance factor must be for its development to be cost effective. Even if resistance is overcome, it still might be a viable short-term management option. Also, for diverse agricultural systems with sufficient refugia of susceptible crops or weed hosts, there is a reduced likelihood that whiteflies will overcome a plant-resistance factor. This is probably the case for most vegetable growing areas of the southeastern USA where silverleaf whitefly is a problem. It is likely that the most important consideration for the long-term management of PRI is a good understanding of the agricultural systems to where it will be employed. After a whitefly-resistant cultivar is released to the public, we must continue to supply technical information and recommendation to growers, extension personnel, and regulatory agencies to insure its long-term success. Only through continued research and regular re-evaluation of IPM programs can this pest be effectively managed, irrespective of the control technology employed.

Investigator's Name(s): S. G. Muigai and D. J. Schuster.

Affiliations & Locations: University of Florida, Gulf Coast Research & Education Center, Bradenton, Florida.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: 1996.

Mechanisms of Resistance of Wild *Lycopersicon* Germplasm to the Silverleaf Whitefly

Cuttings of individual plants in three accessions of *L. pennellii* (LA 1340, LA 1674 and LA 2560), five accessions of *L. hirsutum* f. *typicum* (LA 386, LA 1353, LA 1777, PI 127826 and PI 127827) and one accession of *L. hirsutum* f. *glabratum* were evaluated in no choice experiments for their effects on adults of the silverleaf whitefly (SLWF) in the greenhouse. Adults were confined on whole leaflets in cylindrical, acrylic cages or on portions of leaflets in clip cages. Significantly fewer SLWF adults and eggs were observed on leaflets of the wild genotypes relative to leaflets of the cultivated tomato cv. Solar Set. About 90% of the SLWF adults on leaflets of Solar Set were on the abaxial surface whereas 70% of those on leaflets of the wild genotypes were on adaxial surfaces. Of the adults on leaflets of the wild genotypes, 77-100% were dead whereas only 4% of those on leaflets of Solar Set were dead. Adults on leaflets of the wild genotypes were stuck in the exudates of glandular trichomes. When SLWF adults were confined on Solar Set leaflets which had been appressed onto leaflets of the wild genotypes, oviposition was significantly reduced relative to undisturbed Solar Set leaflets. Oviposition was most affected on those leaflets appressed with *L. pennellii* leaflets.

Selected chemical constituents of glandular trichomes of *L. hirsutum* were bioassayed for repellency, fumigation toxicity and residual toxicity of SLWF adults in the laboratory. The repellency of 2-undecanone was higher than that of 2-tridecanone (RC_{50} values of 6.53 and 0.03 $\mu g/cm^2$ leaf surface, respectively); however, the two compounds demonstrated similar levels of fumigant toxicity (LC_{50} values of 0.008 and 0.005 μg per fumigation chamber). There was no repellent activity or fumigation toxicity of 2-pentadecanone at any dose evaluated. The residual toxicity of 2-pentadecanone was slightly greater than that of 2-tridecanone (LC_{50} values of 10.72 and 16.42 $\mu g/cm^2$ leaf surface, respectively). Two-undecanone could not be assayed for residual toxicity because residues were sticky and entrapped adults at any dosage evaluated.

Investigator's Name(s): Kelli Nafziger, Allen C. Cohen, Eric T. Natwick, C. C. Chu, G. Simmons, D. Brushwood, and T. J. Henneberry.

Affiliation & Location: USDA-ARS, Western Cotton Research Laboratory, 4135 E. Broadway Road, Phoenix, AZ 85040.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: March 1996 through December 1996.

Characteristics of Leaves of Cotton Varieties in Relation to Whitefly Feeding Biology

Seventeen cotton varieties were analyzed for characteristics related to whitefly feeding. Leaves were analyzed from plants sown at the UC Desert Research & Extension Center. The varieties analyzed were DP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 9050, DPX 9057, NuCOTN 33b, CB 1135 and CB 1233 from the US; and CS 50, Siokra L23 V-15, Siokra 1/649, 87031-126 and 89013-114 from Australia. Measurements were made of leaf thickness, distance from lower leaf surface (abaxial surface) to the nearest point on minor vascular bundles, number of minor vascular bundles per unit of leaf surface, thickness of epidermal cells and number of gossypol glands per unit of leaf surface. The differences between these characteristics are discussed in terms of potential resistance to whiteflies in light of what is known of the geometry of whitefly feeding.

Investigator's Name(s): Eric T. Natwick[1], C. C. Chu[2], A. C. Cohen[3], G. Simmons[4], and D. Brushwood[5].

Affiliation & Location: [1]UCCE DREC, Holtville, CA; [2]USDA-ARS-WCRL, Brawley, CA; [3]USDA-ARS-WCRL, Phoenix, AZ; [4]USDA-APHIS, PPQ WR, Brawley, CA; [5]USDA-ARS CQRS, Clemson, SC.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: March 1996 through December 1996.

Effects of Cotton Variety Selection and Insecticide Treatments on Silverleaf Whitefly Infestation Levels

Seventeen cotton varieties were sown at the UC Desert Research & Extension Center into plots of a randomized complete block design experiment with split plots, replicated four times, and irrigated 20 March, 1996. Varieties included in the trial included: DP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 9050, DPX 9057, NuCOTN 33b, CB 1135, and CB 1233 from the US; and CS 50, Siokra L23, Siokra V-15, Siokra 1-4/649, 87031-126, and 89013-114 from Australia. Individual plots measured 14 m in length with 8-beds on 1 m centers. Plots were split into sub-plots of 4-beds each with insecticide treatments being assigned at random to 4-beds in each plot. Insecticide treatments of Danitol 2.4 EC at 0.02 lb ai/a tank mixed with Orthene 90 S at 0.5 lb ai/acre were applied as a foliar spray a total of seven times at weekly intervals starting 11 June, 1996. Helena Buffer PS at 23.6 ml/5 gal. and Sylgard 309 at 5.9 ml/5 gal. used with all insecticide spray treatments. Silverleaf whitefly adults were sampled from five plants at random in each plot via the leaf turn method using the 5th main stem leaf from the terminal on 17 & 24 June, and 1, 8, 16, & 29 July, 1996. Silverleaf whitefly eggs and nymphs were counted on two leaf disks of 1.25 cm^2 from five 5th position leaves down from the terminal extracted from randomly selected plants in each plot on 17 & 24 June, and 1, 8, 16, 22 & 29 July, 1996. Yield data were recorded on August 28, 1996. Seed cotton was hand picked from 0.002 acre per plot. Cotton samples were ginned and lint samples have been sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

All sub-plots receiving the insecticide treatments had significantly lowers ($P \leq 0.05$) numbers of whitefly adults and nymphs on all sampling dates than the same varieties from the sub-plots that did not receive the insecticide treatments with no significant interactions between varieties and insecticide treatments. All but CS 50 and Siokra 1-4/649 among the Australian varieties had the lowest seasonal means for whitefly adults among all of the entries in the trial. All but CS 50 among the Australian varieties had the lowest seasonal means for whitefly eggs and nymphs among all of the entries in the trial. DP 5461 had a significantly lower seed cotton yield than DP 50, NuCOTN 33b, DP 5415, and DP 20 ($P \leq 0.05$; SNK). There were no other differences among the cotton varieties for seed cotton yield.

Investigators' Name(s): R. G. Percy[1], P. C. Ellsworth[2], and H. S. Moser[3].

Affiliations & Locations: [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ, 85040; [2]University of Arizona, Department of Entomology, Maricopa Agricultural Center, Maricopa, AZ, 85239; [3]University of Arizona, Department of Plant Sciences, Maricopa Agricultural Center, Maricopa, AZ, 85239.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: April 1995 - September 1996.

Silverleaf Whitefly Resistance Screening in Pima Cotton Genotypes

An evaluation of silverleaf whitefly preference among 22 Pima cotton genotypes varying in pubescence, leaf shape, leaf size, foliar color, and maturity time was conducted in the field at Maricopa, AZ in 1995 and 1996. In 1995, test plots consisted of single row plots, 9.1 m long, separated by two rows of the commercial cultivar, Pima S-7. In 1996, test plots consisted of four row plots, 9.1 m long, separated by two rows of Pima S-7. Plots were planted in a three replicate, randomized complete block design in both years. Whitefly sampling in both years began in early June and continued through the end of August. Adult whiteflies were counted on the fifth mainstem leaf below the apical meristem on 10 plants per plot. Leaf discs were removed from 5 leaves per plot for determination of egg, nymph, and leaf trichome numbers. Trichomes were counted as individuals, regardless of whether they were uniseriate, biseriate, or stellar. A subset of 10 genotypes (differing primarily in trichome number) were used to define the linear relationships between leaf trichome density and whitefly egg, nymph, and adult populations. The linear relationships were then used to identify trichome density independent sources of plant resistance to the whitefly.

In 1995, linear relationships were obtained between leaf trichome density and whitefly egg and nymph numbers for the trichome range of 0-40 trichomes/in^2. Within the above range, several genotypes were identified which deviated significantly from the established linear regressions. A crinkle-leafed mutant was identified which produced egg and nymph populations in excess of those predicted by its trichome numbers, indicating increased susceptiblity. A smooth, okra-leafed entry produced significantly fewer egg and nymph numbers than predicted for it by its trichome density, indicating an elevated level of resistance. Reduced egg and nymph numbers which approached significant deviation from the established linear relationships were observed in two red plant genotypes. The extremely glabrous entries Sea Island St. Vincent, DPL 5415, and *Gossypium thurberi* exhibited very low whitefly egg and nymph populations which conformed to the linear relationships between trichomes, eggs, and nymphs. The use of the linear regression to identify trichome independent whitefly resistance sources appears to be a successful methodology and should prove useful in further efforts. Analyses of 1996 data continue, as does analyses of whitefly behavior in no-choice cage experiments initiated in 1996.

Investigator's Name(s): David G. Riley.

Affiliation & Location: Coastal Plain Experiment Station, Dept. Entomology, P.O. Box 748, Tifton GA 31793.

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: January 1992 - December 1996.

Melon Cultivar Response to Whitefly Attack

Differences between cultivars were detected in melon trials from 1992-1995 at Weslaco, Texas in the levels of silverleaf whitefly oviposition and nymphal development under field conditions. Tam Sun, HMX 9583, Explorer were associated with moderate to relatively high SW numbers, but provided the greatest yield and harvested dollar value, suggesting tolerance. Melon sizes were affected to a large degree by the presence of SW. The plant introduction 125966 in the 1994 test, a hairy-leaf melon, showed tolerance to SW in terms of vine growth. Yield differences in 1994 were dramatic between the commercial cultivars and PIs, but also between certain commercial cultivars. Glaborous melons in 1995 were resistant to whitefly oviposition and development. The measurements of yield response in these trials provided some initial information on the relative resistance of melon cultivars to whitefly damage. Some consistent, relative differences in preference and antibiosis were indicated by egg/adult and large nymph/egg ratios, respectively. For example, Hymark, Explorer and Cruiser had consistantly lower nymph/egg ratios suggesting some antibiosis. Positive correlations occurred between long-leaf trichomes and numbers of whitefly adults and immatures suggesting that hairiness increased SW preference. A glaborous melon reduced oviposition and nymphal development. In melons, leaf trichomes seem to affect whitefly populations similarly to the presence of leaf trichomes in cotton, that is that smooth leaves appear to reduce whitefly attack.

Investigator's Name(s): Gregory S. Simmons[1], Eric Natwick[2], C. C. Chu[3], Allen Cohen[3] and Don Brushwood[4].

Affiliation & Location: USDA-APHIS-PPQ, Western Region, Brawley, CA[1]; University of California Cooperative Extension Holtville, CA[2]; USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ[3]; USDA Cotton Quality Research Station, Clemson, SC[4].

Research & Implementation Area: Section E: Crop Management Systems and Host Plant Resistance.

Dates Covered by the Report: January 1996 to December 1996.

Effect of Cotton Cultivar on Parasitism of Silverleaf Whitefly by *Eretmocerus* sp.

Four replicate blocks of 17 cultivars of cotton were grown in a randomized complete block design with pesticide and no-treatment as a split factor at U.C. Meloland field station to determine if cultivar type had any effect on parasitism of silverleaf whitefly by naturally occurring *Eretmocerus* sp. The cotton plots were four rows wide by 20 ft long. Plots were twice sampled in July and August. On each sample date, six node 8 leaves (counting down from the terminal leaf =0) were collected from each treated and non-treated plot. Random samples were collected from the inner two rows of each plot, three leaves per row. Samples were examined in the laboratory and all whitefly pupae, emerged whitefly, *Eretmocerus* pupae and emerged *Eretmocerus* were counted within a 2.7 cm^2 disk placed at the base of leaf sector 1. Percentage of parasitism was calculated by dividing the total number of *Eretmocerus* by the total number of *Eretmocerus* plus emerged whitefly. For analysis, percentage of parasitism was transformed using the arc-sine transformation. A split-plot analysis of variance was performed using insecticide treatment as the split factor. Where significance was found, means were separated using Tukey's HSD mean comparison procedure.

On 23 July, there was a significant effect of cultivar type on levels of parasitism ($F = 4.51$ df = 3,16, $p < 0.001$). In the non-treated plots, parasitism levels ranged from 24 to 68%. The highest levels of parasitism were observed in cultivars Siokra L23 and 87031-126 of 68% and 65% respectively. These levels were significantly higher than several of the other cultivars. There were no significant interaction terms.

On 8 August, parasitism in non-treated plots ranged from 36 to 66% and there was a significant effect of cultivar on levels of parasitism ($F = 1.85$ df = 3,16, $p < 0.05$). However, no significant differences were found among means as the Tukey's mean separation test is more conservative than analysis of variance which does not control for experiment-wise error rate.

There were no significant cultivar by insecticide treatment interactions on either date, though insecticide treatment had a significant effect on parasitism on 23 July ($F = 11.14$ df = 3,1, $p < 0.002$). No significant effects of insecticide treatment on parasitism were found on 8 August ($F = 0.56$ df = 3,1, $p < 0.46$). Parasitism levels in the insecticide treated plots ranged from 8 to 58% and 26 to 70% on 23 July and 8 August respectively.

In conclusion, it appears that there may be some effect on cultivar type on levels of parasitism as some cultivars had consistently high levels of parasitism on both sample dates. Cultivars Siokra L23 and 87031-126 may have some useful trait that makes them more attractive to parasites or perhaps renders silverleaf whitefly more susceptible to attack. It should be noted that due to the large size of the experiment very few sample leaves were selected from each plot (n =6). This may have resulted in poor estimates of the true levels of parasitism. Also it should be noted that in three out the four replicate blocks the plots with cultivars Siokra L23 and 87031-126 were adjacent to each other. Though it seems unlikely, if there was some pattern of *Eretmocerus* distribution within the field based on plot location rather than cultivar type, this spatial arrangement of plots may have led to spurious results.

TABLE E. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section E: Crop Management Systems and Host Plant Resistance

Research Approaches	Goals Statement	Progress Achieved: Yes	Progress Achieved: No	Significance
E.1 Determine effect of traditional crop production inputs on SLWF population development.	Year 5: Develop methods that are grower acceptable to minimize SLWF damage and maximize profits.	X		Research conducted on evaluation of the effect of water stress on whitefly populations has been accepted and implemented by cotton growers. Integrating the use of reduced water stress by weekly irrigation and conventional insecticides has provided the best control. Irrigation also reduced whitefly flight behavior compared with water stressed plants. Fiber quality was improved in terms of micronaire values in weekly irrigated plots.
E.2 Determine temporal and spatial effects of host plants on SLWF populations and dispersion.	Year 5: Develop best strategy for cultivated host sequences that will minimize SLWF damage to crops.	X		Efficiency was improved for a spaciotemporal model for simulating whitefly dynamics. Resource maps were generated for the SLWF from Landsat data. The model was used to explore SLWF dynamics in the Imperial Valley agricultural system.
E.3 Determine effect of colored mulches, trap crops, intercropping, row covers, and other innovative cultural practices as potential SLWF control methods.	Year 5: Incorporate best potential factors into system and determine effect on SLWF and crop net returns.	X		Work was conducted on the use of fine net tunnels, reflective silver mulch, green plastic mulch, repellents, and living soil covers. Silver plastic mulch delayed the incidence of tomato mottle geminivirus on tomato by reducing early whitefly infestation. The use of fine mesh tunnels produced virus-free tomato transplants for 30 days, and silver plastic bed covers were effective in suppressing whitefly populations in tomatoes and delaying the dissemination of geminivirus. None of the 19 natural plant extracts repelled whitefly adults; however, 9 caused mortality ranging from 87% to 96%. A new trap, "C.C." trap was found to be highly selective for whitefly while preserving parasitiod populations in cotton.
E.4 Develop reproducible evaluation techniques to isolate resistant germplasm.	Year 5: Continue characterization of resistance mechanisms.	X		Work was conducted on resistance mechanism in azalea, cotton, cole crops, melon and tomato. Leaf thickness was found to be highly correlated with the depth of vascular bundles in cotton and may be developed as a resistance mechanism. Reduced frequency of vascular bundles in leaves may also be developed as a resistance mechanism. Work on other resistance mechanisms in cotton includes reduced trichomes numbers and okra-leaf shape. Glossy collards had fewer whiteflies than waxy leaf collards. Selected chemical constituents of glandular trichomes of *L. hirsutum* were bioassayed for repellency, fumigation toxicity and residual toxicity of SLWF adults.
E.5 Identify resistant germplasm to SLWF and associated viruses and plant disorders.	Year 5: Continue evaluation of selected plant types for management of SLWF.	X		Field trials were continued on identifying resistant germplasm for several crops. Two of 17 cotton lines had reduced numbers of SLWF adults eggs and nymphs, and had higher percent parasitism. Twenty-two Pima cotton genotypes varying in pubescence, leaf shape, leaf size, foliar color, and maturity time were evaluated for preference of SLWF.

Research Approaches	Goals Statement	Progress Achieved		Significance
		Yes	No	
E.6 Conduct plant breeding studies to select SLWF resistant plant germplasm.	Year 5: Continue the transfer program.	X		Alfalfa germplasm with whitefly resistance and other good qualities should be available for seed increase by industry soon (ca. 1998-99). Whitefly-resistant F_2 broccoli lines are being back crossed with commercial cultivars to improve agronomic characteristics. Cotton germplasm, a glabrous type, with whitefly resistance and good yield and other good qualities was released to industry and is now commercially marketed as Texas 121.

Reports of Research Progress
Section F. Integrated Techniques, Approaches, and Philosophies
Co-Chairs: Dennis Kopp and John Norman

Investigator's Name(s): J. C. Allen[1], D. N. Byrne[2], J. F. Paris[3], and D. G. Riley[4].

Affiliations & Locations: University of Florida[1], University of Arizona[2], California State University Fresno[3], University of Georgia[4].

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1996.

Large Scale Dynamics of the Silverleaf Whitefly in the Imperial Valley California

1 . A Model for Silverleaf Whitefly Dynamics in Large Cropping Systems.

OBJECTIVE: Improve the efficiency of a spatiotemporal model for simulating whitefly dynamics.

Improvements were made to a model developed for studying insect dynamics in crop-grid spatial resource systems. The modified model uses whitefly parameter maps generated from resource maps instead of a parameter lookup table. This modification meant that within each time step in the model, the dispersal function was only applied once instead of individually for each crop. When this version of the model was tested on whiteflies in a multi-crop system, the dynamics were no different from those observed before this modification was made. However, simulation efficiency was vastly improved.

2. Resource maps for SLW in the Imperial Valley Agricultural System.

OBJECTIVE: Generate resource maps for the SLW from Landsat data.

Four Landsat subscenes on the Imperial Valley , CA for the 1994-1995 cropping season were acquired for the following dates: 1 September 1994, 21 December 1994, 23 February 1995, and 30 May 1995. Globally positioned ground-truth data were collected as close as possible to the subscene dates , i.e., 1 September 1994, 10 December 1994, 1 February 1995, and 13 May 1995. We used these ground-truth data to create training sets (rasters) that were applied to a supervised Gaussian Maximum Likelihood classification of SLW resources in the Valley. The overall accuracy of the classification results for each date was greater than 95%. After filtering and resampling, the classified rasters were used to generate resource maps that defined the structure of SLW resources in the Valley. These maps are an important part of a spatially explicit population model (SEPM) that was used to study SLW dynamics in the Imperial Valley.

3. SLW dynamics in the Imperial Valley Agricultural System.

OBJECTIVE: Use the model to explore SLW dynamics in the Imperial Valley system

SLW dynamics in the Imperial Valley was studied with a SEPM. Resource maps created from the satellite data were used to generate parameter maps for the whitefly, and several scenarios were then tested with the model. Model results showed that regional SLW populations increased in early- to mid-spring where growth was exponential. A decline in population levels occurred in late June followed by an increase in August and September and a decline near the end of the calendar year. These trends were consistent with what has been observed for SLW in the Valley. Simulations were also used to determine the influence of specific crops on SLW abundance. Removal of alfalfa had the biggest effect on the SLW causing a 6.4-fold reduction in population levels. Removal of summer alfalfa (simulated alfalfa dry-down) caused a 2.8-fold reduction. This was followed by cotton removal that resulted in a 1.3-fold decrease, and the removal of spring melon that reduced SLW populations by a factor of 1.1. The importance of alfalfa in any SLW management program in the Imperial Valley was highlighted by these simulation studies.

We would like to acknowledge the USDA NAPIAP and USDA/SRIPM programs for their support of these studies.

Investigator's Name(s): Steve Castle and Tom Henneberry.

Affiliations & Locations: USDA-ARS, Western Cotton Research Lab, Brawley, CA & Phoenix, AZ.

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 20th Century.

Factors Contributing to Increases of *Bemisia tabaci* Populations: Defining the Outbreak Pyramid

The escalation of *Bemisia tabaci* outbreaks in frequency, destructive intensity, and numbers of locations throughout the world have focused much attention on broad aspects of *Bemisia* spp. biology and management. Explanations for the upsurge in *B. tabaci* outbreaks have often centered on failures of management, in particular as related to the disruptions in control brought about by excessive insecticide use. Although other elements of *B. tabaci* population dynamics are clearly recognized, there has been no synthesis of the fundamental factors that contribute to *B. tabaci* outbreaks.

The Outbreak Pyramid represents a conceptual synthesis of four principle factors that determine the size of *B. tabaci* infestations. The pyramid shape is a useful vehicle for presenting the four factors in an hierarchical manner depicting the layering of one factor upon another. As the most fundamental and unalterable component, **Climate** forms the basal layer of the pyramid. Building off climate are the types of crops grown and their seasonality, etc., representing the **Agriculture** layer. Overlayering both agriculture and climate is the **Biotic** layer, representative of the intrinsic capacity of *B. tabaci* to exploit the resources available as determined by the agricultural makeup and within the physical environment as defined by the climate. At the pinnacle of the pyramid is the **Management** layer, representing the sum of chemical, cultural, and biological controls, and the layer subject to the most manipulation by humans.

The essence of the outbreak pyramid is that in circumstances where the basal two layers of the pyramid are "broad" with environmental potential, the biotic characteristics of *B. tabaci* permit exploitation of the resource base in excess of the various types of control, both natural and manipulated. Conceptually, the volume of the management layer at the top of the pyramid is dwarfed in comparison to the combined volume of the three layers that form the pyramid base. In practice, management efforts that are targeted at individual fields, even if they provide superior results, are soon overwhelmed by region-wide population increases of *B. tabaci* on crop and non-crop vegetation. It is not a failure of management per se to control regional populations of *B. tabaci*, but rather a function of the combined potential contained within the climate, agriculture and biotic levels of the pyramid that eventually exceed the capacity of locally-based crop protection. A reduction in the breadth of any one of the lowest three levels, as occurs seasonally with cooler winter temperatures or in agricultural systems with less suitable crop hosts, will act to alter the shape from pyramid to cylinder.

Comparative Systems Approach

While many regions in the world have been impacted by severe infestations of *B. tabaci*, these represent only the latest in a series of *B. tabaci* outbreaks world-wide dating back to the 1920s. Accounts of historical *B. tabaci* infestations provide an essential perspective on present day outbreaks by demonstrating serious pest potential under a range of agricultural and management conditions. The set of observations on damaging infestations by *B. tabaci*, historical and modern, allows for a broad consideration of factors that determine the size of *B. tabaci* populations in agricultural systems. When contrasted to agricultural regions with only endemic populations of *B. tabaci*, an even more complete picture of manifold factors becomes possible. Two approaches have been taken for comparing *B. tabaci* infestations in various systems. One has been the comparison of modern outbreaks with historical outbreaks by examining published accounts of both. Historical documentation of *B. tabaci* outbreaks prior to 1940 establish their capacity as serious agricultural pests. Explanations for modern outbreaks of *B. tabaci* have often emphasized excessive insecticide use as the causative factor to the exclusion of virtually all else. However, records of destructive *B. tabaci* infestations prior to the advent of organic insecticides establishes their long history as primary pests. The second approach has been to examine outbreak vs. non-outbreak regions in present times to attempt to deduce principle factors contributing to *B. tabaci* outbreaks. *B. tabaci* occurs in agricultural zones around the world, but do not reach outbreak status in all. It is instructive to examine infestations in the various regions and contrast their physical and cultural features for clues concerning different potentials for whitefly infestations. California has served as a good model for comparing different regions because of its agricultural diversity. Substantial differences among three valleys were revealed, especially in the climate and agriculture layers of the outbreak pyramid.

Investigator's Name(s): C. C. Chu, T. J. Henneberry, E. T. Natwick, and A. C. Cohen.

Affiliation & Location: USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ; and University of California Cooperative Extension Service, Holtville, CA.

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1995 - 1996.

Selection of Cotton Varieties to Reduce Insecticide Applications for Silverleaf Whitefly Control

Studies conducted from 1995 to 1996 showed that cotton cultivars were different in their susceptibility to silverleaf whitefly colonization. When whiteflies were controlled at a threshold of 4.1 adults per leaf turn, lint yields of cultivars tested were similar, but numbers of Danitol-Orthene mixture insecticide applications applied to each cultivar were different. In 1995, based on the 4.1 adult threshold, 4 to 5 insecticide applications were applied to Deltapine (DPL) 5415 and DPL 5461 while 6 to 7 applications applied to Stoneville 474 and Louisiana 887. In 1996, based on the same threshold, the two Deltapine cultivars were treated 7 times and Stoneville 474 and Louisiana 887, 8 times.

Investigator's Name(s): Peter Ellsworth[1,2] Steve Naranjo[3], and Jonathan Diehl[1,2].

Affiliations & Locations: University of Arizona, [1]Maricopa Agricultural Center, Maricopa, AZ; [2]Department of Entomology, Tucson, AZ; [3]USDA-ARS Western Cotton Research Lab, Phoenix, AZ.

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1996.

Implementation and Dissemination of Sampling and Threshold Protocols for Whitefly Nymphs in Cotton

Sampling models developed by USDA-ARS and University of Arizona scientists were adapted for use by growers and pest control advisors (PCAs) and provide the basis for the University of Arizona Cooperative Extension Publication: IPM Series Number 6, Sampling Sweetpotato Whitefly Nymphs in Cotton. This protocol outlines decision-making plans needed for use of the changing whitefly management technologies available in Arizona, specifically, the two insect growth regulators (IGRs) Applaud® and Knack®.

The sampling protocol requires counting the number of large (3rd and 4th instar) nymphs visible to the naked eyes within a 3.88 cm2 leaf disk wedged between the main vein and the first lateral vein of the 5th main stem leaf down from the terminal. This area may be approximated by a 7/8 inch inner diameter washer, a U.S. quarter, or a credit card hole-punched with a No. 14 cork borer. Thirty leaves are counted per field. It is recommended that this sampling technique be used along with counts of adult whiteflies when timing the application of IGRs. The recommended threshold for using IGRs is an average of 0.5 -1 nymph per disk with at least 3-5 adults per leaf.

The nymphal sampling protocol was evaluated within a 178-acre whitefly management trial at the Maricopa Agricultural Center. Thirty plants were sampled weekly from each of 48 approximately 4-acre plots. In addition, after counts were made leaves were collected for verification of nymph counts under the microscope. Precision was adequate for densities of 1.0 large nymph per leaf and greater, but sample sizes greater than 30 are needed for lower densities. The ability of samplers to detect and categorize nymphal instars and sampler-to-sampler variation in this ability were significant sources of variation. A binomial (presence/absence) sampling plan may diminish sampler-sampler variation while increasing efficiency and accuracy of decision-making.

These sampling plans were introduced to over 700 growers and PCAs in six training sessions held throughout Arizona. In addition, 2 field workshops were held. Three thousand copies of the extension publication were distributed in Arizona, California and northern Mexico. This publication was sponsored by Cotton Incorporated and the USDA CREES Western Region IPM Program. Plans are underway to translate this publication into Spanish. Sampling and decision-making protocols were widely used in Arizona and facilitated the successful incorporation of the two IGRs into whitefly management practices in Arizona cotton.

Investigator's Name(s): Peter Ellsworth[1,2], Tim Dennehy[2], Jonathan Diehl[1,2], Mike Ansolobehere[8], Larry Antilla[9], Don Howell[3], Steve Husman[4], Tim Knowles[5], Ed Minch[10], Arden Palmer[11], Mark Roland[12], Sam Stedman[6], Gary Thacker[7].

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Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1996.

Statewide Training Sessions for Use of Insect Growth Regulators in Arizona

In 1996, the Arizona Cotton Growers Association, Arizona Department of Agriculture, scientists from The University of Arizona, Cotton Incorporated, industry and others collaborated to develop a Section 18 proposal which included emergency exemption from registration of two insect growth regulators (IGRs), Knack® and Applaud®. The Section 18 was drafted to allow only single use of each material, require a minimum interval between use of the two IGRs, and require training before a grower or pest control adviser could use the insecticides.

In order to satisfy the training requirement of the Section 18, six IGR training sessions were held in Arizona. Over 700 growers, pest control advisers, and applicators were trained in the use of IGRs. Training sessions included presentations on sampling and thresholds, resistance management, regulatory requirements, and industry support and development, and a demonstration on mode of action of the two IGRs. Training sessions were hosted by The University of Arizona Cooperative Extension county agents and presentations were conducted by representatives from The University of Arizona, the Arizona Department of Agriculture, the Arizona Cotton Research and Protection Council, the Arizona Cotton Growers Association, AgrEvo, and Valent.

Investigator's Name(s): Jose L. Martinez-Carrillo and J. J. Pacheco-Covarrubias.

Affiliations & Locations: INIFAP-CIRNO, Entomology, Apartado Postal 515, Cd. Obregón, Son., México.

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1992-1996.

Research Review on Silverleaf Whitefly in Northwestern Mexico

Silverleaf whitefly (SLWF) has become one of the most important insect pests in Mexico. This insect has damaged several crops and eliminated some such as soybeans and sesame from the agricultural crop systems, where they were planted before the outbreaks of the SLWF.

In 1991 an outbreak of the SLWF occurred in the Mexicali valley causing severe damage to watermelons, cantaloupe, sesame and cotton. In 1992 damage was even worst affecting seriously cotton production. Since then this insect has moved south damaging various crops in the agricultural areas of northwestern Mexico. Actually it has been reported from 15 states in Mexico with different degrees of damage.

In order to reduce the problems with the SLWF in northwestern Mexico, a pest management project was initiated in 1993. This project has seven areas where research and actions have been taken. These areas are as follows: Biology and Ecology, Insecticide Management, Biological Control, Management of Production Systems, Validation, Capacitation and Diffusion.

There are two publications under the title "Mosquita Blanca en el noroeste de Mexico 1993 and 1994" which contain resume of results of research experiments established under the SLWF management project No. 622. These publications can be obtained by writing to the above address. Data obtained through this experiments, information published by different institutions at the national and international level, experiences expressed by technicians, growers and scientists has been put together in order to take actions at the regional level to reduce the damage caused by this insect pest. SLWF technical groups have been formed in the different agricultural areas of northwestern Mexico. They are responsible for analyzing data, and suggest the actions that have to be implemented at the regional level. In these groups participate Agricultural authorities, pest control advisors, growers and scientist. Up to now the SLWF problem has been reduced but not eliminated in northwestern Mexico.

Investigator's Name(s): D. Ritter, R. C. Weddle, and S. L. Birdsall.

Affiliation & Location: Imperial County Whitefly Program Coordinator, Entomologist, and Imperial County Agricultural Commissioner, respectively, El Centro, CA.

Research & Implementation Area: Section F: Integrated Techniques, Approaches, and Philosophies.

Dates Covered by the Report: 1996.

Evaluation of CC Whitefly Trap for Monitoring of Adult Whitefly Population Densities in an Agricultural Environment

Yellow sticky card traps have been widely used for monitoring seasonal migrations of adult whitefly populations for several years. Because of the sticky material used on the cards, they can be troublesome to handle and count. The cards are readily contaminated by foreign objects such as dust and other insects and can become saturated with adult whiteflies which can distort the data. Many of these problems have been eliminated by the development of a new whitefly trap (C Trap) by C. C. Chu and T. J. Henneberry. This trap is easier to handle, there are no messy materials to apply, it is whitefly specific and total adult whiteflies trapped are significantly lower to allow for easier counting. We tested the CC Trap and a similar trap, the Trappit Dome Trap in the Imperial Valley in 1996. In February 1996, thirty traps each were installed at five-mile intervals along the main perimeter and down the north-south center of the Imperial Valley Farmland. Traps were monitored weekly and catches were averaged for each trap typed. Results indicate that the CC trap can catch whitefly adults and the weekly catches appear to follow the seasonal increase of population densities from February to September. Dome traps are also useful, but numbers of adults caught by the trap were less than that of the CC trap by a factor of 8.

TABLE F. SUMMARY OF RESEARCH PROGRESS IN RELATION TO YEAR 5 GOALS OF THE 5-YEAR PLAN (1992-1996)
Section F: Integrated Techniques, Approaches and Philosophies

Research Approaches	Goals Statement	Progress Achieved: Yes	Progress Achieved: No	Significance
F.1 Whitefly risk assessment.	Year 5: Support risk assessment system and develop management procedures.		X	Only minor progress has been made on this approach. The following can be related regarding this approach: • Fluctuation in populations have been seen from season to season yet predictability is presently not possible. • To effectively assess risk of this pest in the future, we must first: a) develop a more complete understanding of the role of different host plants in whitefly population development; b) better understand plant mechanisms of host plant resistance to whitefly; c) develop, improve, and validate enhanced methodologies of whitefly sampling in order to monitor population development and dispersal; d) develop a broader understanding of the genetic basis of insecticide resistance in whitefly populations and incorporate this knowledge into management systems; e) develop community wide Integrated Management Systems that manage *Bemisia* and other production pests with minimal environmental impact in each threatened crop; and f) apply economic values to each of the above.
F.2 Spatial analysis and GIS.	Year 5: Operate system under new framework of administration. Troubleshoot activities.	X		Progress in this approach has been made in the following areas: • Methods for mapping crop systems from satellite (Landsat) image data were developed and applied to the San Joaquin, Imperial and Lower Rio Grande Valleys. • Methods of interfacing satellite based crop maps with insect simulation models have been developed and used in simulations.
F.3 Ecosystem modeling.	Year 5: Transfer activity to state institutions and assist in specific activity.	X		Progress in this approach has been made in the following areas: • New methods of modeling and visualizing spatial dynamics have been developed which use the fast Fourier transform for solving the spatial dispersal/reproduction process in a spatial model of whitefly dynamics making it possible to use of PCs for simulation of spatially extended systems. • A satellite image analysis system (TNTmips) has now been installed at Kearney Agricultural Center in the San Joaquin Valley. A full Landsat scene (100x115mi) of the Valley (July 3, 1994) has been provided thus demonstrating the potential of this technology to producers. • Field Sampling in Texas, Arizona, and California is being used to validate prediction capabilities of whitefly population models.

Research Approaches	Goals Statement	Progress Achieved: Yes	Progress Achieved: No	Significance
F.4 Networks.	Year 5: Transfer national activities to permanent institution support.	X		Progress in this approach has been made in the following areas: • A broad network of whitefly information is linked on the WWW with homepages in Arizona, California, Florida, and Texas. • New collaborations in research and extension have been forged nationally between Florida, Arizona, Texas and California, and a strong informal international cooperative effort has developed amoung scientists in Mexico, Arizona, and California. • Implementation and new management technologies are being shared with scientists in other countries. This was demonstrated by the broad participation, information sharing and networking of US scientists in the 1st International Whitefly Workshop in Israel in 1994. These US scientists presently occupy key leadership roles in the planning and development of the 2nd International Whitefly Workshop in San Juan, PR scheduled for June 1998. • The annual whitefly meeting of this group of scientists is an example of effective networking in itself.
F.5 IPM program implementation.	Year 5: Transfer system to permanent support such as State Department of Agriculture, Cooperative Extension Service, commodity groups, private groups and troubleshoot system. Emphasize new sampling and threshold guidelines for IGR use, product efficacy, and resistance management.	X		Progress in this approach has been made in the following areas: • Whiteflies are an important component in cotton and vegetable IPM programs which have been implemented in Arizona, Mexico, California, and Texas. Growth and acceptance is visible in each program as they expand in geographic area and crops covered. • A national effort has been made to distribute and share extension developed whitefly management educational publications and resource materials produced by scientists in Arizona, California, Florida, Mexico, and Texas. • A "train the trainer" program was developed and implemented in California and Arizona, which did much to strengthen the ties and cooperation between growers, extension and research scientists. • Satellite crop map information is being coupled with and related to pest population data, climatic data, whitefly population migration data, spatial distribution, and pest management data. This information is being targeted to IPM implementation programs as they relate to crop sequencing for community wide management approaches. • A state regulatory agency (Arizona Dept. of Agriculture) and a commodity group (Arizona Cotton Growers Association) took responsibility for stewarding a progressive Section 18 process which enabled uses of selective *Bemisia* growth regulators, namely Applaud® and Knack®. Cooperative Extension through industry collaboration developed the section 18 and implemented a pro-active educational program.

IV. New Silverleaf Whitefly Research, Action and Technology Transfer Plan

The overall orientation of the new research and technology transfer plan is for development of integrated pest management strategies for incorporation into existing community action plans and for the development of new areawide and IPM efforts. The research community, within the framework of the new plan, is charged with the responsibility of providing new knowledge and developing innovative, novel, adaptable approaches for silverleaf whitefly areawide and integrated pest management programs. The basis for community-based pest management programs resides in a comprehensive knowledge of natural mortality regulating population factors; impact of natural enemies, and potential for augmentation, and conservation and introduction of new natural enemies, and development of other effective control strategies where applicable. The new plan strongly supports biological, biologically-based control approaches, host plant resistance, and their implementation. More than 30 natural enemies, including fungi, are in various stages of colonization and evaluation to determine their potential as control agents. Cultural control, biologically-based strategies, and host-plant resistance offer the most socially and environmentally acceptable technologies for use in integrated management programs. The plan stresses research to fill gaps in our knowledge base that prevent our full understanding and potential manipulation of the whitefly complex including: environmental response and plant interactions in cultivated crops, urban and nursery plantings, and weed ecosystems. Fundamental research in genetics, biochemistry, molecular biology, virus and virus transmission, and behavior is needed to provide a research base upon which to sustain long-term integrated management programs.

A major effort in technology transfer under the new plan will be directed to development of area-wide and IPM community-involved programs that will take advantage of compatible and effective suppression components acceptable to the environmentally concerned, and the farming community. The major responsibility for this effort will be absorbed by federal and state action and regulatory agencies, university cooperative extension services, and the leaders within the agricultural commodity associations. Growers must be full partners in all aspects of the programs. Such programs will also rely heavily on expanded efforts of education-extension to develop far reaching technology transfer and provide the necessary communication to our clientele on progress and products available for implementation. The new plan consists of 6 priority research sections, and provisions for annual reporting on outcomes, impacts, and products delivered or under development.

OBJECTIVES

The new plan provides a transition from the completed "5-Year National Research and Action Plan for Management and Control of the Silverleaf Whitefly, *Bemisia argentifolii*" to a new research and technology transfer plan for the years 1997 through 2001. It provides a continued basis for communication, coordination, and cooperation, and for generating ideas, identifying knowledge gaps and research needs, setting priorities, and facilitating the transfer of information and technology for management and control.

The specific objectives of the new research and technology transfer plan are to:

- Provide a forum for discussing and evaluating SLW research program progress, and for describing delivered end products.
- Enhance team-based communication, coordination, and cooperation between research, methods development, extension, and education components in order to address SLW management issues.
- Identify knowledge gaps and clarify research needs, opportunities, and strategies for use in integrating interdisciplinary, interagency, and industry resources in the management of silverleaf whitefly.
- Serve as a decision base for progressive reassessing of priorities as the need arises.
- Describe new technologies, and transfer deliverable technologies to clientele.
- Facilitate community-based partnerships for implementation of areawide SLW management programs.

TECHNOLOGY TRANSFER

Technology transfer will be discussed at each progress review and updated as necessary. The tables will include delivered products, products being developed, and the impacts and outcomes of the technology transfer. Technology transfer will be accomplished through meetings, workshops, training sessions, cooperative research and development agreements, agricultural experiment station mailings, and USDA and state experiment station networking systems.

A. Biology, Ecology, and Population Dynamics

Current Research Activities

Generalized silverleaf whitefly host plant sequences on cultivated crops, urban plantings, weeds, and native plants from spring through winter have been identified and are being studied in relation to population dynamics. Seasonal population trend studies have shown differences in whitefly magnitude on various host species and among locations and years; however, the overall trends in hosts utilized and sequence have been similar among locations and years. The mediating influence of the environment has been the overriding influence on whitefly density. Initial population dynamics modeling efforts have been made and serve to identify needed research. Initial modeling studies in multiple crop systems indicate that population simulations compare reasonably with trends observed in sampling data, and were highly sensitive to natural enemy parameters. LandSat data obtained for the Imperial Valley and San Joaquin Valley of California are being ground-truthed. Appropriate simulations may eventually be used to study the influence of areawide management practices, and host plant interactions on SLW populations. This will involve extensive study and validation.

Considerable research progress has been made in developing and delivering sampling plans and in relating SLW densities with cantaloupe and cotton yields and cotton lint stickiness in relation to action thresholds. These plans provide a base for growers, pest control operators and researchers in development and implementation of action thresholds. The cotton sampling plan was validated in more than 8000 acres of commercial production. The cotton and melon sampling plans have been implemented in IPM programs in the United States and internationally. Sampling plans and decision-making tools are a necessity for all cultivated hosts and should be continually refined, improved and updated in light of newly developed control options. In cotton and cantaloupe, key components that influence economic injury and economically based thresholds have been suggested. Action thresholds should greatly benefit growers in making management decisions and are essential for other crops. SLW sampling plans and action thresholds are being developed for cole crops, tomatoes, and alfalfa. Whitefly action thresholds for lint stickiness and quality losses in other crops are less well-defined. Initial studies correlating cotton photosynthesis (and resulting yield) with SLW densities have been accomplished but results need to be quantified, and related to other plant measurements. The technique will help to further refine the threshold and to better understand the insect-plant interaction and may provide a linkage with whitefly-induced plant disorders and whitefly-vectored virus stresses on crop plants.

SLW dispersal abilities are being quantified in relation to environmental conditions (wind) and agronomic factors (water stress). Knowledge of SLW dispersal and movement influencing factors will be important considerations for designing efficient management schemes. This will be a key research area as areawide management schemes are designed and implemented.

Behavioral studies of whitefly feeding have revealed information that may provide clues to methods of manipulating these vital feeding functions in plants through conventional plant breeding or molecular approaches to incorporating resistant characteristics into acceptable agronomic crop types. Feeding behavior of first-instar immatures of several whitefly species show activities related to host plant structure and effects on morphology of later instars. Results from adult behavioral studies have suggested a potential new trap design which is badly needed for survey and monitoring since sticky traps are difficult to use, time consuming to count and can only be used for very short-term exposures.

Histological study of stylet penetration has correlated with host plant microstructure and plant morphological characteristics. Surface and internal structures of leaves from different host plant species and cultivars have been shown to affect immature whitefly morphology and ability to colonize (density of immatures) and feed. The latter is probably due to variation in density and proximity of available vascular bundles within leaves. Serine proteinase activities were undetectable in whole extracts of whiteflies, but other enzymes, especially those secreted into the plant, may affect host plant responses significantly.

Whiteflies showed differences in mating behaviors among species. If extended to studies of *B. tabaci* populations, this may have relevance to the reproductive isolation observed between biotypes. The absence of clear morphological differences between *B. tabaci* Strain B and *B. argentifolii*, and differences of opinion as to the validity of molecular genetics approaches for making species level determinations remains unresolved. Key morphological characters by which the A, B, and other biotypes can be distinguished are still lacking. Morphological plasticity and data from several molecular studies indicate the most likely classification for the group is as a *B. tabaci* species complex, with the common name sweetpotato whitefly. Some morphological plasticity stems from stimuli received by crawlers based on plant geography, hairiness, and crowded conditions on the leaf. Clearly, this insect is more complex than previously realized.

Carbohydrate analyses of whitefly honeydew has revealed several new oligosaccharides, and more clearly defined the composition of honeydew. The role of these materials as by-products of biochemical mechanisms in the whitefly is unknown. Continuing studies with endosymbionts, enzymes and physiological characterization need to be done to identify potential weak links in biological systems that might be manipulated between the insect and host as a possible control approach. A possible solution might be the use of specifically constructed enzymes that would hydrolyze *Bemisia* sugars on cotton lint. Some work has been initiated but it is preliminary in nature and needs expanded objectives. Several artificial whitefly feeding systems have been developed. These systems have been used to rear whiteflies from egg to adult for the first time. Fundamental biological studies have been conducted to evaluate the effects of insecticidal compounds and antibiotics on whiteflies (presumably, antibiotics affect primary endosymbionts), and to study the transmission

pathway of geminiviruses in adult whiteflies in relation to feeding behavior. Feeding chambers have also been utilized in the identification of sugars that contribute to stickiness due to whitefly honeydew. Recent development of artificial feeding systems and diets may allow mass rearing of natural enemies. Whiteflies were shown to be unsuitable prey for some predators, due to nutritional deficiencies. The availability of the artificial feeding systems opens the door to numerous studies on nutrition, digestion, metabolism, biochemistry and physiological relationships.

Knowledge Gaps

1. Knowledge of key factors in overwintering mortality and environmental and biological parameters stimulating population increases is limited and life table analysis is needed.

2. Identification of life cycle vulnerabilities that may be manipulated for population management have not been found.

3. Economic thresholds, except for cotton and cantaloupe, have not been addressed.

4. Sampling methods and action thresholds have been developed for only a few major crops.

5. Extensive refinement of existing models needs to be made, to interface with multiple host plant phenology, biological, environmental and other potential control inputs.

6. Sampling for cotton lint stickiness is complex and field sampling needs to be extended; other whitefly induced crop quality impacts need to be addressed.

7. The time of whitefly dispersal, environmental and biological factors affecting dispersal, the proportion of the population that disperses and reproductive efficiency need to be carefully defined to determine the impact of dispersing populations on population dynamics at the source and the end of the dispersal cycle.

8. Whitefly mating behavior needs to be better understood in relationship to reproductive isolation. The marked differences between agricultural effects of biotypes or species of *Bemisia* is not reflected in the current understanding of systematic relationships, although reproductive isolation is often an assumed mechanism. Knowledge of mating behavior may allow prediction and action against population increases with changes in genetic composition.

9. Taxonomic and nomenclatural issues must be clarified to expedite international scientific communication.

10. Endosymbionts are crucial to whitefly survival and reproduction. Enhanced knowledge of endosymbiont biology and function may lead directly to novel control technologies that incorporate endosymbiont disruption, e.g. with antibiotics, and subsequent reduction of whitefly populations.

11. Whitefly artificial feeding and rearing systems are now showing promise and must be developed further. These systems will provide valuable tools for efforts in whitefly control as diverse as mass production of natural enemies, development of new biorational insecticides, discovery of secretions that are central to host plant disorders, and disruption of endosymbionts.

Five-Year National Research and Action Plan Priority Tables, Research Needs, and Yearly Goals (1997-2001)

Table A. Biology, Ecology, and Population Dynamics

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.	Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts.	Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies.	Identify potential low population manipulation on vital host links for survival.	Initiate studies to manipulate host sequences to determine potential influence on whitefly population.	Continue 4 and finalize analysis of the potential of habitat modification as a management tool.
Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.	Initiate whitefly to identify spatial and temporal distributions in major cultivated crops.	Analysis and identification of needed additional sampling research to develop appropriate sampling protocol.	Validate and refine sampling methods.	Implement sampling protocols through cooperative extension outlets and other technology transfer methods.	Finalization, implementation and use in IPM systems.
Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.	Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces.	Begin model development to include all biological and plant phenology data in simulation development.	Provide model simulation of whitefly populations and multiple cropping systems.	Identify weak points and needed information to improve model simulations.	Validate and expand effort to provide predictive models capabilities for whitefly population development and crop interfaces.
Develop sampling methods for quality of cotton lint, vegetables and other commodities.	Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning.	Based on 1, expand and repeat sampling protocols as described.	Develop sampling protocol for field and harvest and processing sampling and determine interrelationships.	Extend sampling protocols to textile mill and verify field findings in relation to mill problems.	Modify, refine and complete sticky cotton sampling protocols from the field to the mill.
Quantify whitefly and natural enemy dispersals and contribution to population dynamics.	Review and analyze existing knowledge of whitefly dispersal.	Validate times of whitefly dispersal, environmental factors and identify modifying factors.	Determine proportion of whitefly population that are migratory and their reproductive potential.	Quantify the role of dispersal in population dynamics on different crop systems.	Formulate theory for manipulating and/or using dispersal as a tool in IPM.
Define mating behavior, reproductive isolation, species, biotypes.	Initiate studies on mating, oviposition and other behavior.	Define interspecies interbiotype mating interactions.	Define factors involved in mating, cues, feedback mechanisms, etc.	Develop potential methods of utilizing behavioral information in management strategies.	Review, summarize and propose additional needed research.
Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.	Continue examination of *Bemisia* sp. for distinct morphological character differences.	Develop genetic molecular level and acceptable species level separation.	Discuss results, plan additional research, arrive at a consensus decision.	Publish verification of new species or other appropriate taxa.	———
Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.	Identify endosymbionts in whitefly.	Determine role of endosymbionts in whitefly biological functioning.	Determine potential for manipulating, interfering with or inhibiting endosymbiont function.	Determine associated enzymes and/or other endosymbionts and whitefly relationships.	Summarize and implement findings with suggestion for additional research.

Five-Year National Research and Action Plan Priority Tables, Research Needs, and Yearly Goals (1997-2001)

Table A. Biology, Ecology, and Population Dynamics

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Characterize nutrient uptake and metabolism.	Determine the process of uptake and metabolism of carbohydrates, amino acids and other nutrients.	Determine the various enzymes involved in uptake and metabolism of essential nutrients.	Characterize the genes that encode for key enzymes of whitefly nutrient metabolism.	Determine the potential for manipulating the activities or expression of key enzymes.	Evaluate potential for transforming plants to disrupt whitefly metabolism.
Develop whitefly artificial diets and natural enemy mass-rearing.	Identify whitefly nutritional components in plant tissue.	Develop whitefly artificial feeding systems.	Conduct addition, deletion studies to identify essential nutritional needs.	Evaluate developed diets on whitefly fecundity/longevity biology, behavioral characteristics.	Develop whitefly rearing system and adapt for production of natural enemies.

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

B. Viruses, Epidemiology, and Virus-Vector Interactions

Current Research Activities

The whitefly-transmitted geminiviruses (Subgroup III Geminiviridae) pose an extremely serious threat to agricultural systems within the habitat range of *Bemisia*, in the US and in adjacent regions of Mexico, as well as the Caribbean Basin. These viruses were recognized as a new group of virus pathogens in 1978, and during the last decade have become recognized as globally occurring in a variety of food and fiber crops. At present, whitefly transmitted (WFT) geminiviruses have made serious inroads into agricultural systems in Arizona, California, Florida, and Texas of the US and in adjacent regions in the subtropical agroecosystems throughout the Americas. Hence, the potential for the occurrence of new diseases and epidemics caused by geminiviruses is now greater than ever. Geminiviruses that predominate as plant pathogens in the US include: cotton leaf crumple geminivirus in Arizona and California cotton crops, squash leaf curl geminivirus throughout Arizona in melons, squash, and watermelon plantings, and in watermelon in the Rio Grande Valley, Texas.

In addition, numerous uncharacterized whitefly-transmitted geminiviruses have been detected in crop and weed species in Arizona and in the Rio Grande Valley of Texas, including new geminiviruses of cotton, kenaf, okra, and tomatillo. In Florida, bean golden mosaic, tomato mottle geminivirus, and cabbage mottle geminiviruses are economically important in bean, tomato, and cabbage crops throughout the state. Two whitefly-transmitted viruses of tomato and lettuce have been described and appear to be distinct from geminiviruses. Most of these viruses remain unstudied or poorly understood, despite some effort to investigate the respective diseases.

Considerable progress has been made in developing polymerase chain reaction (PCR) assays to specifically and universally detect subgroup III geminiviruses. PCR primers target the core or central fragment of the coat protein (CP) gene and yield a 550 bp diagnostic product. The products are cloned and sequenced, and incorporated into the geminivirus CP gene sequence database. This approach has greatly facilitated geminivirus identification and is an essential tool for molecular epidemiological studies.

The relationships between WFT viruses and their whitefly vectors are characterized as either persistent and circulative for geminviruses, and semi-persistent or non-persistent for the few representative non-geminiviruses known to be vectored by whiteflies. The geminviruses predominate worldwide among WFT-transmittted viruses as important pathogens in agroecosystems. Very little is known about the mechanisms involved in this process. Preliminary studies have been conducted that will lead to elucidating the underlying mechanisms involved in the process, and to understand the basis for geminivirus-whitefly specificity in transmission of geminiviruses. Several laboratories have begun to establish experimental systems by which to study these important interactions.

A novel micro-feeding chamber has been developed and used to examine several accessible steps in the transmission pathway between the vector whitefly, *Bemisia*, the non-vector, greenhouse whitefly, and the squash leaf curl geminivirus. PCR was used to amplify a diagnostic fragment of SqLCV coat protein to demonstrate presence of the virus. In time-course studies, virus was detected in whole body extracts, honeydew, and saliva of the vector, whereas, in the non-vector, virus was detectable in body extracts and honeydew, but never in saliva. This result provides the first evidence of geminivirus in whitefly vector saliva and paves the way for additional evaluation of the transmission process using this novel approach. Several laboratories have developed assay systems that utilized PCR to detect geminivirus DNA in individual whiteflies given sufficient acquisition access periods on infected plants.

A method for preparing whole whiteflies for light and electron microscopy examination, and for immunocytochemistry has been developed. Adult whitefly anatomy was studied using this method of preparation, and a detailed functional anatomical interpretation has been put forth. Immunocytochemistry studies using antibodies to the whitefly-transmitted squash leaf curl virus was applied for locating the virus and to elucidate specific aspects of geminivirus-whitefly vector interactions. Labeled antibody was detected in most organs and fluids of adult whiteflies, and several hypotheses about virus-vector specificity, with respect to postulated anatomy were also put forth.

The utility of key morphological characters for differentiation of subtaxa within the *Bemisia tabaci* species complex was revisited. Results of an extensive, high resolution TEM study in which key characters of a suite of *B. tabaci* populations examined indicated no significance differences in any character or character combination that permitted separation of populations into subtaxa, including distinct species. The ASMS4 setae, has been proposed as a diagnostic character, and universally absent or present, to differentiate A and B biotypes (also *B. argentifolii)*. In this study, ASMS4 setae were neither consistently absent in populations from the Eastern Hemisphere or from the Old World B biotype, nor consistently present in all New World populations. However, the ASMS4 setal pair was more often absent in Old World populations, and when, present, it was most often associated with a New World whitefly, indicating that the trait is clearly not as definitive as originally proposed. In addition, other characters used to identify *B. tabaci* to genus and species, varied for different host-plant species, and/or with the absence of, or degree of leaf pubescence, and with degree of crowdedness.

Genetic analysis by RAPD-PCR and a mitochondrial 16S DNA marker postulated to distinguish between subtaxa or lower, indicate a high degree of polymorphism between distinct populations, and extend similar conclusions drawn from general esterase electromorph patterns. Further, using both methods, most populations examined clustered by either a New or Old World origin, but several interesting

collections are either split, or form a continuous distribution, depending on type of analysis applied to data sets. Thus, it still appears that there is inadequate data upon which to base taxonomic decisions about the *B. tabaci* species complex at subspecies levels, or with regard to universal acceptance of the proposed species novae, *B. argentifolii,* for a population also known as B biotype.

Knowledge Gaps

1. Identification and characterization of virus-vector relationships of economically important whitefly-transmitted viruses, with an emphasis on geminiviruses, presently recognized as the most important emerging group of plant viruses in US crops.

2. Molecular epidemiological information: geographic virus distribution, identification of economically important and predominant viruses, specific plant hosts and natural sources in agroecosystems, virus reservoirs, and alternate virus hosts.

3. Factors affecting whitefly-mediated virus transmission, including a possible role for endosymbionts and their relation to the transmission process, the pathways traversed by specific viruses in the vector, the basis for virus-vector specificities, and their impact on disease epidemiology.

4. Management strategies to reduce the spread of whitefly-vectored viruses and/or the impact on disease incidence. Strategies may involve interference with whitefly-mediated transmission processes, development of resistant or tolerant germplasm through classical breeding approaches and/or development of transgenic plants with anti-viral capabilities, and management of diseases through a practical knowledge of virus identity, distribution, virulence, host range, molecular epidemiology of important diseases, and the potential for economic damage.

5. Definition and assessment of the impact of genetic and biological variability between whitefly vector types or *Bemisia* species on whitefly-mediated transmission/disease spread; genetic based methods are needed to identify and differentiate economically important whitefly biological types and/or *Bemisia* species (within the proposed *B. tabaci* species complex).

6. Molecular engineering approaches to develop plant resistance to whitefly-transmitted viruses.

Table B. Viruses, Epidemiology, and Virus-Vector Interactions

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Identification and characterization of new or emerging whitefly-transmitted viruses and strains	Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation.	Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods.	Continue etiological studies and virus characterization. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution.	Continue etiological studies and virus characterization efforts. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution.	Summarize and review results. Determine areas of new research.
Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.	Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking.	Continue field studies. Determine economic input of diseases on crop production and associated losses.	Establish geographic distribution of viruses and identify sources of inoculum. Assess role of alternative host virus reservoirs on spread of diseases.	Identify and characterize virus involvement in disease establishment and spread. Assess potential methods of reducing virus reservoirs as a method of reducing disease.	Review and make recommendations for further research and potential implementation of results.
Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission	Initiate studies on virus-vector interactions and on basis for the specificity of whitefly-mediated geminivirus transmission.	Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission.	Continue studies in progress to determine specific factors involved in virus transmission, and the role of endosymbionts in virus acquisition and transmission.	Continue virus-vector interactions studies toward the development of approaches for disease control.	Summarize findings and suggest new research needs; implementation of existing knowledge.
Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.	Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution.	Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	Continue studies of management approaches for disease abatement. Focus on interdisciplinary studies in conjunction with whitefly control methods in Sections B and C.	Evaluate strategies for crop management and impact on disease epidemiology.	Evaluate approaches and identify areas of future research for disease control by management of cropping systems. Linkages with IPM approaches.
Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.	Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars.	Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses.	Further identification of resistant germplasm and develop new methods of incorporating resistance into crop plants. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection.	Continue development of resistant varieties. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. Define mechanisms of resistance.	Evaluate resistant plants in greenhouse and field experimentation, and identify additional research. Molecular-based monitoring of transgenes in environment.

Table B. Viruses, Epidemiology, and Virus-Vector Interactions (continued)

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.	Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatibilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex.	Continue to study differences in species/ strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular, & genetic terms. Infer molecular phylogenies from molecular markers.	Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections.	Identify potential factors related to specific genetic and biological variability that may be manipulated to reduce disease spread. Develop molecular approaches to track biotypes, strains, and species relative to disease spread, based on differential molecular markers.	Summarize results, identify new research needs and make recommendations for implementation or expansion of research.

C. Chemical Control, Biopesticides, Resistance Management, and Application Methods

Current Research Activities

Chemical control approaches can be valuable IPM tools that help maintain or improve crop yields. Yield responses to chemical control have been demonstrated in virtually all host crops for a variety of insecticides. The ability of chemical control to maintain SLW populations below economic thresholds has been demonstrated in cotton and melons, and chemical control of geminivirus epizootics has been achieved in tomatoes. Action thresholds help limit indiscriminate use of insecticide, and have been established for cotton (5-10, adults per leaf) and cantaloupe (3 per leaf). These values need to be constantly refined and updated in response to changing conditions of crop ecology, control efficacy and market economics.

A major goal now is to preserve and improve the efficacy of insecticidal tools and enhance integration with other management strategies. Genetic, biochemical and ecological mechanisms of insecticide resistance need to be better elucidated to achieve successful resistance management. Widespread monitoring for resistance has underscored the fact that problems are most likely to occur in closed systems like greenhouses and desert agriculture with no refuge for susceptible populations. Although rotation of available chemistries is undoubtedly useful in slowing selection for resistance, rotation alone did not reverse trends expressed by whitefly populations in a large scale experiment conducted in Maricopa county in 1995-96More selective chemistries, including natural products and other biopesticides, could fit into insecticide rotations to better manage resistance. Experimentation with hydraulic and air assisted ground applications or electrostatic charging of spray material applied by ground or air has not resulted clear cut advantages between methods. However, underleaf coverage can always be improved by optimizing pump pressure, spray volume, and nozzle configuration of conventional hydraulic systems, thereby enhancing efficacy of selective contact materials such as detergents and mycoinsecticides

Where available, alternatives to broad-spectrum insecticides should be encouraged to conserve natural enemies and advance the integration of biological and chemical control. Responses of parasitoids and predators to specific chemicals and biopesticides need to be constantly evaluated, and compatibility tested in the field. The potential for synthesis of these compounds in transgenic plants needs to be evaluated through extensive biochemical and genetic analysis.

Knowledge Gaps

1. Information is needed on more efficacious, diverse, and selective chemistries and natural products to control whiteflies.

2. Action thresholds for most cultivated crops have not been developed and current developed thresholds need to be related to specific insecticide usage patterns.

3. More efficacious method of applying insecticides are needed to improve coverage of selective, inexpensive and environmentally safe contact materials.

4. Methods to preserve the efficacy of existing and new chemicals must be developed. Resistance mechanisms need to be identified and resistance management strategies developed with biochemical, genetic, and ecological resistance factors considered.

5. Timing, rates, placement, and insecticide selectivity must be improved to conserve natural enemies and provide opportunities for biological control. Guidelines for integration of chemical and biological control need to be developed and tested.

Five-Year National Research and Action Plan Priority Tables, Research Approaches, and Yearly Goals (1997-2001)

Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Improve insecticide efficacy:					
• **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.**	Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies.	Same as Year 1. Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products.	Same as Year 2. Evaluate the potential for transforming plants with natural product genes.	Same as Year 3.	Same as Year 4.
• **Develop improved methods of application including formulation and delivery of materials to improve control.**	Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer.	Same as Year 1.	Same as Year 2.	Same as Year 3.	Same as Year 4.
Conserve insecticide efficacy:					
• **Relate action thresholds to insecticide usage patterns.**	Refine action thresholds based on insecticide efficacy and input from other control strategies.	Same as Year 1.	Same as Year 2.	Same as Year 3.	Same as Year 4. Summarize and recommend in IPM systems.
• **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.**	Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide.	Same as Year 1. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population.	Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. Evaluate the influence of host plant on susceptibility to insecticides.	Same as Year 3.	Same as Year 4.

Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods (continued)

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Improve insecticide efficacy:					
Improve techniques for monitoring resistance.	Establish baseline data on toxogenic responses of whitefly populations to new insecticides.	Same as Year 1. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy.	Same as Year 2. Summarize, analyze, and produce standardized comparable monitoring systems.	Same as Year 3. Develop standard systems for general use including user friendly techniques to assist growers and extension agents to evaluate susceptibility of whitefly populations to commonly used insecticides.	Same as Year 4.
Develop, evaluate and refine resistance management systems	Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance.	Same as Year 1. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool.	Same as Year 2. Develop criteria for integration of successful strategies in agricultural systems. Field test resistance management systems as long range components of successful IPM.	Same as Year 3.	Same as Year 4. Technology transfer.
Integrate chemical control with other tactics.	Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies.	Same as Year 1. Test compatibility of biological control with selective synthetic or natural product insecticides as required.	Same as Year 2. Integrate systems with host plant resistance and cultural controls.	Test compatibility of biological control with selective synthetic or natural product insecticides as required. Integrate systems with host plant resistance and cultural controls.	Integrate systems with host plant resistance and cultural controls. Summarization and technology transfer.

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Tables E and F for complementary research on systems management.

D. Natural Enemy Ecology and Biological Control

Current Research Activities

Biological control approaches remain the fundamental base for developing long-term integrated whitefly management. Research in this area has resulted in several biological control products that have become commercially available. Natural enemies studied in both agricultural and urban systems include parasitoids, predators, and fungal pathogens. The contributions of natural control, natural enemy conservation, augmentation and importation have been significant but varied. The majority of field studies have been conducted in California, Arizona, Texas, and Florida, while the majority of greenhouse studies have been conducted in California, Florida and the Northeast.

Surveys of indigenous natural enemies (esp. parasitoids) have been conducted for most whitefly infested areas of the US. Experimental data evaluating the impact of indigenous natural enemies on whitefly in the absence of insecticide pressure is generally lacking. Survey data document varying levels of parasitism across a wide range of habitats and individual host plant species, but the manipulative experiments necessary to measure whitefly suppression have not been conducted.

Methods for conserving natural enemies have received relatively minor attention compared to the other forms of biological control. Progress has been made to determine the potential of natural enemy refugia to sustain natural enemies in the field. Research conducted in California has shown that annual plant refuges may lead to increased levels of parasitism by *Eretmocerus* sp. in adjacent crop plants. However, these annual plant refuges may not be practical for the desert Southwest because of poor sustainability and high costs. New studies with perennial plantings will be initiated and need to be intensified.

Identification of physiologically or ecologically selective insecticides has received only minimal attention. Effort should be exerted to quantify the effects of insecticide chemistries and application methodologies on beneficial arthropods, and to select the materials and methods that are least harmful to nontarget species. Little effort has been made to identify variation among natural enemy populations based on their susceptibility to insecticide practices, and no effort has been made to develop insecticide-resistant natural enemies.

Foreign explorations have been extremely successful in terms of making available a wide array of natural enemy species or strains exotic to the US. Quarantine procedures for most of these species are completed, and permits have been issued for release of biological control agents for research. California, Arizona, and Texas have initiated release programs to evaluate several of the parasitoid strains. Evaluation is time consuming and several years of study are required before establishment and impact can be assessed with any degree of confidence.

Molecular methodology for classification of *Eretmocerus* and *Encarsia* has been completed and publications with keys to identify the various parasitoid species are in various stages of preparation for publication. New concerns have arisen regarding the systematics of *Delphastus*. Continued support for natural enemy systematics should accompany the field research associated with importation and augmentation programs, and additional support should be made available to resolve taxonomic issues of the key natural enemies.

Mass-rearing procedures have been developed for some natural enemy species with the potential to produce millions of parasitic wasps for augmentation and release. Artificial diets are being investigated to improve cost-effectiveness of mass-produced predators. A major increase in this area for potentially useful predators and parasitoids must be made if augmentation approaches are to be fully investigated and implemented.

A number of fungi associated with whiteflies have been collected. Several fungi have shown exceptional potential. In field trials, however, results indicate that formulation and application technology need improvement. An effective microbial control component for incorporation in whitefly management systems that could substitute for synthetic chemicals would be a major breakthrough that would greatly improve the probability of success for parasitoid-predator augmentation approaches.

Opportunities for advancement of the science of biological control remain plentiful. The mechanisms leading to the success or failure of biological control should be studied within the context of developing a solution to this important pest. Research on tritrophic interactions among host plants, whitefly, and their natural enemies may be useful in configuring optimal refuges for natural enemy conservation and prioritizing target cropping systems for augmentation or importation biological control. The diverse array of biologies represented by the numerous natural enemy species that may be released during biological control programs provide a unique opportunity to assess the role of interspecific interactions, the development and utility of pre-release evaluations, the identification of species-level attributes, and the value of various release strategies that may facilitate or hinder biological control. These represent only a selection of the numerous opportunities. Given the magnitude of the program in terms of research dollars, facilities, and personnel, the opportunity for advancing the science while solving an agricultural problem should be seized.

Knowledge Gaps

Natural Control and Conservation

1. Quantify the effects of crop management practices, including pesticide use, on the ability of natural enemies to suppress whitefly populations.

2. Develop techniques to enhance natural enemy abundance and effectiveness in urban and agricultural systems.

Augmentation of Natural Enemies

3. Gather information on nutrition, physiology, and ecology of parasitoids, predators, and pathogens essential to cost-effective mass-rearing procedures.

4. Evaluate the efficacy of natural enemies in the greenhouse and field, develop implementation technologies, and assess the economics of biological control methods.

5. Develop storage, shipping, release and quality control technologies to maximize the effectiveness of mass-reared natural enemies in the field.

Importation Biological Control

6. Evaluate establishment and long-term control effects of exotic natural enemies in the field.

Systematics, Ecology and Population Dynamics of Natural Enemies

7. Conduct systematics research of natural enemies present in target release sites and of imported and mass-reared natural enemies.

8. Examine the effects of host plants and plant community structure on natural enemy performance.

9. Identify the attributes of natural enemy biology and population level interactions contributing to biological control success or failure.

Five-Year National Research and Action Plan Priority Tables, Research Approaches, and Yearly Goals (1997-2001)

Table D. Natural Enemy Ecology and Biological Control

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Natural control and conservation:					
• **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.**	Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations.	Identify the spatial scale upon which the key mortality agents are acting.	Conduct manipulative experiments to evaluate the impact of each natural enemy mortality agent on whitefly suppression.	Conduct a feasibility study and economic assessment of altered crop management practices that may enhance the impact of indigenous natural enemies.	Develop and evaluate area wide programs to facilitate full implementation.
• **Evaluate potential of alternate plants it act as in-field refuges or insectaries for natural enemies.**	Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems.	Determine refugia plant phenology in relation to cultivated crop phenology.	Conduct field tests to assess whether refuges act of natural enemy and whitefly sinks or sources to adjacent cropping systems.	Conduct field tests to evaluate spacing of refuges necessary to achieve satisfactory whitefly suppression.	Conduct a feasibility study and economic assessment of alternate plantings in terms of an entire crop management program.
• **Assess cues used by natural enemies to locate whitefly to identify potential methods for enhancing natural enemy activity.**	Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly.	Determine potential methods for manipulating cues as part of a whitefly management program.	Conduct small scale trials to enhance whitefly suppression by manipulating natural enemy location and attack of whitefly.	Conduct large scale field trials and evaluate product development for commercial investment as necessary.	Transfer technology (as needed) to commercial interests for full implementation.
Augmentation of natural enemies:					
• **Develop natural enemy mass-rearing systems.**	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems.	Determine nutritional, physiological, and ecological requirements for mass-rearing.	Develop rearing systems on selected hosts and on artificial diets. Determine economic feasibility of the procedure.	Evaluate rearing system effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations.	Facilitate transfer of mass-rearing technology to commercial interests as necessary.
• **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.**	Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced.	Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released.	Develop necessary technology for release of the appropriate natural enemy life stage.	Evaluate release technology effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations.	Facilitate transfer of mass-rearing technology to commercial interests as necessary.
• **Evaluate augmentative parasitoid, predator, or pathogen releases.**	Initiate studies on natural enemy augmentation with identified high potential natural enemies.	Conduct releases on selected crop systems at various rates of release.	Identify optimal release strategies for key cropping systems.	Continue evaluation of releases, determine need for additional releases. Compare results in different cropping systems and environments.	Analyze information and make recommendation regarding need for expansion of the approach.

Table D. Natural Enemy Ecology and Biological Control (continued)

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Importation biological control:					
• **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.**	Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies.	Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary.	Assess spread of established natural enemies and their ability to suppress whitefly populations.	Continue to assess the spread of established natural enemies and their ability to suppress whitefly populations. Evaluate program progress and determine if additional strategies are necessary.	Complete program analysis. Publish program assessment and conduct an economic assessment.
Systematics, ecology, and population dynamics of natural enemies[b]:					
• **Clarify systematics of predators, parasitoids and pathogens.**	Conduct taxonomic studies of species within targeted release sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis	Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications.	Provide taxonomic support for importation and mass-rearing programs.	Provide taxonomic support for importation and mass-rearing programs.	Provide taxonomic support for importation and mass-rearing programs.
• **Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.**	Initiate studies to identify mechanisms involved in *Bemisia*- and natural enemy plant attraction.	Study plant characteristics mediating whitefly population densities.	Study compatibility of characteristics of plant traits mediating whitefly populations with the abilities of natural enemies to suppress whitefly populations.	Assess the implementability of favorable tritrophic interactions within the context of an whitefly management program.	Implement and evaluate large scale crop management programs for suppression of whitefly populations.
• **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.**	Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control.	In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control.	Assess deviations between theoretical predictions and field data.	Evaluate behavioral or population level parameters that may explain observed deviations.	Quantify the impact of basic research on the development of feasible biological control programs for *Bemisia* and the advancement of the field as a science.

[a] See Table C for complementary research.
[b] See Table A for complementary research.

E. Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions

Current Research Activities

Some degree of plant resistance to whiteflies has been reported for nearly every major crop studied. Limited reports have been made on progress in developing virus disease resistance. Significant progress for incorporating resistance into acceptable agronomic crops is dependent on identifying resistance mechanisms. Some factors influencing host selection have been suggested for cotton and other crops. Leaf thickness was shown to be highly correlated with the depth of vascular bundles in cotton, suggesting a more tedious access for whitefly feeding. Work on other potential resistance mechanisms in cotton identified reduced trichome numbers, okra-leaf shape, and red plant color. A glabrous cotton type with whitefly resistance, good yield, and other desirable qualities, was released to industry and is now commercially marketed as Texas 121. Progress with alfalfa germplasm with whitefly resistance and other good qualities suggested germplasm should soon (ca. 1998) be available for seed increases by industry. For collards, two hybrids had fewer whiteflies than open-pollinated cultivars, but three glossy leaf genotypes were the most resistant. Two zucchini squash lines (Sunseed 3 and A21-7) have been identified with resistance to silverleaf symptoms, but not to whitefly infestations. Resistance sources have not been located in tomato, and foliar pubescence had a variable influence on whitefly populations. In contrast, pubescence was a factor in host oviposition selection and vertical distribution of oviposition on soybean, but whitefly survival and development were not affected.

Information is needed on the concentrations of dietary components in the phloem tissue of various host plants to fully understand host plant preference by the whitefly. It is also important to determine how dietary components change in response to specific changes in plant physiology (i.e., water stress, nitrogen nutrition) that affect whitefly populations. Knowledge of the uptake and metabolism must be acquired to develop strategies for inhibiting feeding functions. Feeding behavior of first-instar immatures of several whitefly species shows activities related to host plant structure and affects on morphology of later instars.

Some biochemical relationships are being revealed that may explain physiological syndromes associated with silverleaf whitefly infestations. Expression pathogenesis related proteins in tomatoes resulted from feeding by whiteflies. Duration of feeding and distance from fruiting structures affected the severity of tomato irregular ripening. α-Tocopherol, squalene, and linolenic acid increased in squash (pumpkin) plants prior to expression of squash silverleaf; these compounds may serve nutritional and/or structural needs of the host plant or the insect.

The universal acceptability of plant resistance as an economic, environmentally desirable solution to pest problems provides justification for expansion of our efforts in this direction. Although, in the past, the time required to develop resistant, agronomically acceptable crops has been long, new genetic and molecular biology methods in conjunction with conventional breeding approaches may significantly expedite the process. Emphasis on the physiology, biochemistry and molecular biology of the host-plant interaction is required to identify key aspects of whitefly metabolism that can be targeted for inhibition by plant manipulation.

Knowledge Gaps

1. Mechanisms of resistance and modes of action for whitefly and disease resistance.

2. Sources of germplasm for use in selection for whitefly resistance, disease resistance and associated physiological traits.

3. Molecular biology approaches for developing whitefly and disease resistance.

4. Definition of whitefly-plant interactions and identification of plant characteristics that may be useful in developing plant resistance approaches to control.

5. Characterization of new plant physiological syndromes that have appeared with the new biotype or with the increase in whitefly populations.

Table E. Host Plant Resistance, Physiological Disorders, and Host Plant Interactions

Approaches/Goals	Year 1	Year 2	Year 3	Year 4	Year 5
Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.	Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a]	Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm.	Elucidate biochemical and molecular basis for resistance. Continue to identify resistant germplasm.	Determine potential for transfer of resistance traits.	Evaluate potential for incorporating *Bemisia*, plant disorder and disease resistance into acceptable plant type.
Develop molecular level techniques to produce resistant germplasm.	Identify physiological processes of whiteflies to target for inhibition.	Identify natural products for inhibiting processes.	Isolate the relevant biosynthetic enzymes that encode for natural products inhibiting processes.	Insert genes into plants via plant transformation.[b]	Evaluate potential of newly transformed germplasm.
Incorporate resistance traits into commercial genotypes.	Identify and isolate genetic sources of resistance for transformation and/or breeding.	Insert genes into plants[b] via plant transformation.	Evaluate potential of newly transformed germplasm.	Continue to refine resistance factors to improve resistance in newly transformed germplasm.	Incorporate other desirable plant characteristics for crop production.
Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[c]	Characterize nutritional and other preference properties of various host plants.	Determine the biochemical mechanism regulating adaptation to host plants.	Determine changes in whitefly gene expression in response to host manipulation.	Relate changes in gene expression to whitefly physiology.	Summarize and disseminate results.
Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[d]	Investigate approaches for interruption of feeding, assimilation, development and reproduction.	Identify physiological and morphological mechanisms regulating processes.	Determine biochemical and molecular basis for inhibiting processes.	Determine potential for transfer of resistance traits.	Insert genes into plants[a] via plant transformation.
Study whitefly toxicogenic plant reactions.	Determine effects of whitefly feeding on host plant physiology, morphology and anatomy.	Determine biochemical basis for physiological response of plant.	Elucidate changes in plant gene expression.	Identify resistance germplasm.	Evaluate potential for transferring new germplasm.

[a] See Table B for additional plant disease resistance research.
[b] Progress at this point may extend to several year research.
[c] See Section A.
[d] See Section A, approach #9.

F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems

Current Research Activities

Many of the cultural and chemical control research achievements have been implemented at some level in one or more farm communities. Integrated areawide approaches are a goal for the future. The wide host range of cultivated, nursery, and ornamental crops and inter an intra crop movement suggests that areawide, community-involved strategies have the best potential for whitefly managment. The role of natural enemies in whitefly population regulation and potential augmentation candidates are being identified. Some information is available regarding chemical control and natural enemy interactions to develop potential conservation strategies. Additionally, natural enemy refugia are being investigated. Sampling protocols and action thresholds for cotton and cantaloupe have been developed and are continually being refined. Resistance monitoring techniques have been developed and implemented and new insecticide chemistry developed that is helping reduce insecticide use and resistance development. Other management approaches with potential as components for IPM systems include cultural practices such as destruction of host crops after harvest, timely irrigation to avoid water stress, and close attention to planting dates and harvest for sequentially planted susceptible crops. These strategies provide a strong base for successful efforts to develop community involved areawide management systems.

To facilitate areawide management approaches, aerial crop mapping of California's San Joaquin Valley, California, is being developed to build better cropping systems. Ground surveys are essential to verify aerial technology analytical potential. Spatial models of cropping systems are being assembled and possible interlinking with precision farming may enhance the research approaches on an areawide basis. Multicrop modeling work has been initiated in Florida and site specific models for examining the impact of multiple control tactics are being developed in Arizona. As chemical, cultural control , biological control and sampling technology becomes refined there remains a vital need for state and federal regulatory and action agencies and university Cooperative Extension to provide implementation pathways, communication and educational systems for the consumer in development of community action plans.

Crop production inputs and management techniques have been found to have substantial influence on silverleaf whitefly population dynamics. The reasons why this occurs are not known, and must be determined if crop management systems are to be developed for optimum yield and minimum whitefly problems. Reduced water stress has been studied extensively in cotton but not in other crop systems. Fertilizer inputs also appear to influence whitefly population development, but again no explanations are evident and results are variable. Little or no information exists for cotton crop production methodology such as plant density, planting dates, harvest dates, and in the case of cotton, such activities as defoliant and desiccant applications. Generally, planting considerations include crop sequencing to extend cultivated host-free periods as long as possible and to identify spatial considerations with respect to existing crops. Current guidelines are vague and need to be defined.

Large scale cropping patterns in relation to reproduction and movement of silverleaf whitefly are being studied in some areas. These studies are utilizing LandSat data to map cropping patterns for modeling the spatiotemporal dynamics of silverleaf whitefly in large cropping systems. Localized migrations by whitefly adults are being studied in cropping systems in western Arizona. These studies have focused on wind patterns, distance adults migrate, distribution of migratory whitefly from a point source, and the ability of whiteflies to reproduce in relation to distance of migration from a point source. Studies on host adaptation show that host source can affect the quality of whitefly populations. These studies are in their infancy, and extensive studies are needed to define areawide cropping systems, impact of diverse ecosystems, and different environmental parameters.

Knowledge Gaps

1. Community and areawide management systems implementation protocols.

2. Understanding of mechanisms involved in irrigation and fertilization crop production inputs on whitefly population dynamics. Lack of information on relationships of other crop production and cultural practices to whitefly population dynamics.

3. Guidelines for multicrop planting sequences in relation to whitefly population development.

4. Information on efficiency of mulches, row covers, and exclusion techniques on crop production and whitefly populations.

5. Improve sampling methodology for decision making in areawide management programs.

6. Mechanisms to guide the transition from local, farm-by-farm focus to community and areawide cooperative efforts.

Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems

Approaches/Goals[a]	Year 1	Year 2	Year 3	Year 4	Year 5
Development:					
Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/ termination/harvest dates, other farm practices, intercrop relationships.	Identify potential beneficial or exacerbating farm practices or inputs for testing.	Determine nature and character of relationship between interaction and whitefly population dynamics.	Identify mechanisms governing relationship and alter or manipulate factors that suppress whitefly dynamics.	Refine system, add other compatible components, evaluate economic impact; conduct field testing and evaluations.	Conduct economic analyses and determine next level of IPM/ICM systems evaluation. Develop recommendations of best management practices.
Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, intercropping, row covers, etc.	Review potential behavioral disrupters and evaluate as potential IPM components.	Conduct field-level trials; quantify impact to crop and whitefly dynamics	Apply promising technologies to high-value crop systems; field test and evaluate.	Refine system, add other components, and conduct economic feasibility analyses.	Summarize and evaluate results; prepare crop systems-specific recommendations.
Integration:					
Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.	Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation.	Initiate field testing of candidate systems.	Continue field testing & evaluate feasibility of large scale testing; add components as necessary.	Initiate large-scale experiments; incorporate economic evaluation.	Evaluate multiple component system as potential deliverable; prepare recommendations.
Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.	Develop or modify sampling systems for new crops; integrate with thresholds and decision-making.	Establish practical utility of system through economic analyses; field efficiencies and costs.	Integrate additional control components into sampling, threshold & decision-making systems	Evaluate in whole field systems. Identify weaknesses; target improvements.	Evaluate redesigned decision systems; continue field testing and economic analyses.
Delivery and Implementation:					
Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.	Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation.	Install control technologies into community; develop systems for evaluation.	Identify additional IPM/ICM compatible components. Re-assess and adapt program. Conduct areawide economic analyses.	Formulate clientele surveys; develop & begin to implement protocols for evaluating areawide technologies.	Refine, reevaluate and identify weaknesses. Formulate recommendations for future areawide management systems. Conduct surveys.
Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.	Develop and distribute provisional IPM & ICM recommendations.	Conduct whole farm/operation demonstrations of IPM systems.	Expand sites of testing with grower cooperators; conduct validation studies.	Incorporate new information and economics into recommendations.	Validate new components; finalize recommendations; expand to new crops.

[a] See Tables A to E for additional complementary research.
[b] See Table A for additional complementary research.
[c] See Table E for additional complementary research.

ADDENDUM

Bibliography of

Bemisia tabaci (Gennadius)
&
Bemisia argentifolii Bellows and Perring



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January 1997

Bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring

Addendum, January 1997

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In 1995 we published a bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring (Butler et al. 1995). This bibliography was compiled from various sources including the current awareness literature service of the National Agricultural Library, Current Contents (Institute for Scientific Information), the two published bibliographies of Cock (CAB International), and the proceedings of several international conferences and symposia. It attempted to cover the world literature through the end of 1994. An addendum to this bibliography was published in 1996 (Naranjo et al. 1996) covering new citations listed during 1995. This 2nd addendum includes citations listed during 1996.

We would like to alert users of this bibliography to several points. First, we have not attempted to abbreviate many of the names of non-US publications and have spelled out some names, especially USA state names, to assist students in other countries. Second, we have not been able to obtain copies of some of the citations and so could not verify spelling, scientific names, irregular punctuation, and accuracy of the location of the reference. We have tried to standardize as much as possible, but our references may not be exactly as given in the original publications.

The 1st and 2nd addenda and the original bibliography were produced using Pro-Cite 2.1.1 for DOS (Personal Bibliographic Software, Inc.). To simplify the distribution of electronic copies, we maintain the January 1997 addendum and the total bibliography (through January 1997). This permits those with the complete database from last year to update through the end of 1996 and those without any of the versions to obtain the entire bibliography. We offer several options for obtaining electronic copies. For those that send us a blank diskette and mailer, we will provide copies of the databases in Procite format (for those that have Procite software) word processor format (specify Word or WordPerfect) or ASCII text format. We can also provide the databases along with a runtime version of the Procite software. This runtime software will enable you to search and print the database. Finally, you can download any of the formats mentioned above from the Western Cotton Research Laboratory World-Wide-Web Homepage, **http://gears.tucson.ars.ag.gov/wcrl/**.

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Appendix B

Minutes of the Silverleaf Whitefly (SLWF) Working Group Meeting

January 30, 1997
Holiday Inn on the Bay, Porthole Room
San Diego, California
1:00-3:00 p.m.

Introductory Remarks:

The meeting was called to order by Robert Faust. Dr. Faust handed out an attendance sheet and discussed guidelines for the meeting. Dr. Faust distributed and reviewed the agenda for the Working Group meeting, and also distributed several handouts, including the Roles and Responsibilities for the Working Group, the new technology transfer product form and example, and an announcement for the International *Bemisia* meeting in Puerto Rico. Attendees were requested to introduce themselves and state their affiliation.

New Committees, Structures and Functions:

A planning meeting was held in New Orleans, Louisiana, in June of 1996, to structure this year's progress review, to put a process together for the transition between the old and new plans, and to put together a process to assemble documentation on technology transfer. At this meeting, it was decided to break the Technical Working Group into two groups: the Program Planning and Review Committee (PPRC), comprised of review coordinators, section chairs, local arrangements personnel, and an advisory representative from the SLWF Coordinating Group; and the Working Group, which has open membership.

The PPRC is responsible for the detailed planning and structure of the annual progress review, including: creating the agenda for the progress review, inviting speakers to the review, assigning local arrangements responsibilities, establishing deadlines, preparing review materials, appointing section chairs with Working Group input, setting meeting objectives, and finalizing the progress review report. The PPRC will meet at least once before each annual progress review, and then again after the review.

Section Co-Chair duties include: serving on the PPRC and Working Group, arranging section papers, setting section goals prior to the annual review, leading section sessions at the annual progress review, ensuring deadlines are met by meeting participants, preparing progress summaries and tables each year, recommending co-chair replacements, and other related responsibilities as needed by review coordinators. The advantages of being a co-chair include: an opportunity for national recognition; an opportunity to drive the future planning of the SLWF research agenda; an opportunity to stay current with research activities across the country; an opportunity to build on communication across research and action areas; and an opportunity for helping to set and prioritize national research issues and needs.

The Working Group's responsibilities include: critiquing the annual progress review, advising the Program Planning and Review Committee, and acting as conduit for communication with the USDA SLWF Coordinating Group. The Working Group will remain a functional entity until the 1998 SLWF progress review when it's status will be re-visited.

Report of Meeting Attendance:

In attendance this year were a total of 175 registrants. Foreign visitors represented were from Canada (2), Costa Rica (1), Dominican Republic (1), Egypt (2), France (1), India (1), Israel (1), Mexico (9), Pakistan (2) and Taiwan (1).

Technology Transfer:

Two new components are being added to the annual progress review reporting process: (1) a summary of technology transfer promulgated during the 5-year research and action program which describes the activity, impact and outcome, and (2) a description of new or potentially new, technology products coming on-line, as well as their significance. Robert Faust and Dennis Kopp plan to distill these two documents down into a shorter version (table form) for use at the Departmental level.

Final Report/Assignments/Deadlines for the 1997 Progress Review Report:

A deadline of February 14, 1997, was set for receipt of all corrected and/or additional abstracts, technology transfer items, new product information, five-year summaries, year-five tables, and revisions to the new plan and tables for the progress review report.

Information should be sent to:

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Lisa Arth requested that the information listed above be transmitted either on disk with a hard copy or via e-mail with a hard copy in both word processing and text formats.

The minutes for the Working Group meeting will be transcribed by Lisa Arth and Marla Lawrence, and then sent to Dr. Faust for review. These minutes will be included as an appendix in the final progress review report.

1998 Progress and Technology Transfer Review/Section Chair Appointments/Location:

The section chairs for the 1998 progress review will be as follows:

Section A	Jon Allen and Steve Naranjo
Section B	Robin Huettel and Doug Maxwell
Section C	Tim Dennehy and Phil Stansly
Section D	Kevin Heinz and Charles Pickett
Section E	Eric Natwick and Alvin Simmons
Section F	Peter Ellsworth and John Norman

Tentative Meeting site: Charleston, South Carolina. Alvin Simmons will take the lead on local arrangements.

Dates: Dates will be either the end of January or the beginning of February, and will be determined by site availability.

Structure of 1998 meeting: The format for next year's meeting will be determined by the PPRC.

International Activities:

Dr. Faust noted that the International *Bemisia* meeting is scheduled to be held in Puerto Rico on June 7-12, 1998. Dr. Dick Mayer provided the conference participants with an announcement brochure and asked that the registration forms in the brochure be returned as soon as possible so that an estimation of the numbers of participants can be obtained.

Issues for the USDA SLWF Research, Education and Implementation Coordinating Group/Membership changes:

The Coordinating Group is the pipeline between administrators/legislators and the researchers. Currently there are 2 members from ARS, 2 members from APHIS, and 2 members from CSREES. There was some discussion about who should represent the State Agricultural Experiment Stations. The Working Group recommended Nick Toscano and Judy Brown be SAES representatives on the Coordinating Group, with Kevin Heinz rotating in next year.

Other Business:

Dennis Kopp suggested that there needs to be a better mechanism for increasing industry, particularly nursery and greenhouse, participation in the annual progress review conference. It was suggested that we reinstate in the program review agenda an industry component.

Jim DeQuattro from the ARS Information office plans to prepare a one-page summary of the whitefly review for the media. He will draft a document and present it to the group for editing. There was also some discussion about producing a slick brochure to hand out to interested parties. UC Riverside has agreed to put a draft together.

Dr. Faust adjourned the Working Group meeting at approximately 3:00 p.m.

Respectfully submitted,

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Enclosures:
- SLWF Working Group Meeting Attendees
- Questionnaire on the Future of the 5-Year Plan
- SLWF Working Group—Roles and Responsibilities

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Questionnaire on the Future of the 5-Year Plan

Future Activities of the National Research and Action Program for Development of Management and Control Methodology for the Silverleaf Whitefly (SLWF)

The 5-Year National Research and Action Plan for Silverleaf Whitefly was formulated in late 1991 to early 1992. In 1997, the 5-year period will come to a close. The SLWF Technical Working Group and the USDA SLWF Coordinating Group would like to receive your thoughts and suggestions on what the post-action plan activities should be. Please provide your comments and suggestions using this questionnaire to either Robert Faust, Tom Henneberry, or Nick Toscano by Monday evening, February 5, 1996. Please feel free to attach additional pages, if necessary. Your comments will be discussed during two special planning meetings of the Technical and Coordinating Groups on the evening of February 6, 1996, and at later planning sessions.

1. Should another action plan be put in place as a part of the 1997 progress review? Please explain.

2. Is there a need for an IPM-technology transfer plan to be formulated as a result of the technologies (or anticipated technologies) generated and what should be the nature of such a plan? (e.g., what will be the technology transfer products, who will be the responsible group, and what are the benchmarks?)

3. Should the frequency of planning sessions and progress reviews remain on an annual basis after 1997? What should be the frequency of meetings? Should planning sessions and progress reviews be continued or should they be terminated after 1997?

4. Other comments and suggestions on the future structure, process and activities of the program.

Name _____ (optional)

Silverleaf Whitefly Working Group—Roles and Responsibilities

WHEREAS, the silverleaf whitefly, *Bemisia argentifolii,* also known as the sweetpotato (SPWF), cotton, poinsettia, cassava, and tobacco whitefly, has become a serious pest of cultivated and greenhouse crops in the United States, in addition to being a vector of certain disease-causing viruses; and

WHEREAS, the U.S. Department of Agriculture (USDA), functioning through the Agricultural Research Service (ARS), the Animal and Plant Health Inspection Service (APHIS), the Cooperative State Research, Education and Extension Service (CSREES), the Economic Research Service (ERS), including the State Agricultural Experiment Stations, conducts or otherwise supports research and methods development programs for the management and mitigation of the impact of the silverleaf whitefly in the United States; and

WHEREAS, the USDA has already established a National Research and Action Program Plan for Development of Management and Control Methodology for the Silverleaf Whitefly, as well as a Working Group, such a program requires close coordination among the participants to ensure unified goals and to generate technology to reduce the impacts of the silverleaf whitefly;

BE IT THEREFORE AGREED:

1. That a Silverleaf Whitefly Working Group be responsible for the following objectives:

   (a) To keep the USDA SPWF Research, Education & Implementation Coordinating Group apprised of the consortium's progress in research, education, and implementation;

   (b) To help plan and critique progress reviews and other workshop activities, and to facilitate the evaluation of relevant information generated under the program;

   (c) To help arrange and set the time and place for annual progress reviews and other needed workshops related to SLW, to select key individuals to serve as meeting coordinators, and to appoint section co-chairs, local coordinators, and *ad hoc* committees, as needed;

   (d) To help prepare annual progress workshop reports and other appropriate periodic reports;

   (e) To monitor the progress of the National SLW Research and Action Plan and any developments that may influence the goals of the Plan.

   (f) To help coordinate the various components of the National SLW Research and Action Plan, and to review, formulate, and make recommendations related to the management and operation of activities within the program, including technology transfer;

   (g) To identify research, education and implementation issues and concerns;

   (h) To help set priorities based on outcomes of progress reviews and other inputs; and

   (i) To help formulate and implement post 5-Year National SPWF Research and Action Plan strategies and activities.

2. That the Silverleaf Whitefly Working Group will be composed of members from each of the services (ARS, APHIS, CSREES, ERS), the State Agricultural Experiment Stations, State Departments of Agriculture, commodity groups, private industry, and other appropriate representatives as deemed necessary by the SLW Working Group. A representative from one of these institutions will serve as the Chair of the Working Group.

3. That the SLW Working Group will meet not less than one time a year at locations and times to be determined, preferably in conjunction with the SLW Annual Progress Review. Minutes of the meeting(s) will be published and distributed to interested parties.

4. That the SLW Working Group will identify innovative ways to further coordination, cooperation, consensus building, and maintenance of a unified research and implementation effort until the SLWF problem is mitigated.

Appendix C

Meeting Agenda

FIFTH ANNUAL PROGRESS REVIEW OF THE 5-YEAR NATIONAL RESEARCH AND ACTION PLAN FOR DEVELOPMENT OF MANAGEMENT AND CONTROL METHODOLOGY FOR SILVERLEAF WHITEFLY

Monday, January 27, 1997 - Travel Day

12:00 noon	Poster set-up begins (Pacific Ballroom C)	
1:00-8:00 p.m.	SRIEG 87 (Captain's Room 3)	

Tuesday, January 28, 1997

7:00 a.m.	REGISTRATION (Pacific Ballroom Lobby) CONTINENTAL BREAKFAST (Pacific Ballroom C)	

PLENARY SESSION (PACIFIC BALLROOMS A & B)

8:00 a.m.	Welcome	*Nick C. Toscano*
8:15 a.m.	Charge to Conference	*Tom J. Henneberry*

SECTION RETROSPECTIVE PRESENTATIONS: 5-YEAR REVIEW

8:20 a.m.	Section A: Ecology, Population Dynamics, and Dispersal	*David N. Byrne*
8:50 a.m.	Section B: Fundamental Research--Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions	*Judith K. Brown*
9:20 a.m.	Section C: Chemical Control, Biorationals, and Pesticide Application Technology	*Philip A. Stansly*
9:50 a.m.	BREAK	
10:00 a.m.	Section D: Biological Control	*Kevin M. Heinz*
10:30 a.m.	Section E: Crop Management Systems and Host Plant Resistance	*Alvin M. Simmons*
11:00 a.m.	Section F: Integrated Techniques, Approaches, and Philosophies	*Peter Ellsworth*
11:30 a.m.	Technology Transfer	*Robert M. Faust, Dennis D. Kopp & Thomas M. Perring*
12:30 noon	LUNCH	

BREAKOUT GROUP MEETINGS

2:00-5:00 p.m.	Concurrent Meetings (Sections A & B in Pacific Ballrooms A & B, respectively) 10-minute presentations of submitted papers
6:00-8:00 p.m.	Mixer and Poster Session (Pacific Ballrooms C & D)

Wednesday, January 29, 1997

7:00 a.m.	CONTINENTAL BREAKFAST	
8:00-12:30 p.m.	Concurrent Meetings (Sections C & D in Pacific Ballrooms A & B, respectively) 10-minute presentations of submitted papers	
12:30 p.m.	LUNCH	
2:00-5:00 p.m.	Concurrent Meetings (Sections E & F in Pacific Ballrooms A & B, respectively) 10-minute presentations of submitted papers	

Thursday, January 30, 1997

7:00 a.m.	CONTINENTAL BREAKFAST	

PLENARY SESSION (PACIFIC BALLROOMS A & B)

Review & Discussion of Outlines and Development of a New Research and Action Plan

8:00 a.m.	Changes in the New Plan	*Thomas M. Perring*
8:15 a.m.	Section A: Biology, Ecology, and Population Dynamics	*Larry Godfrey*
8:45 a.m.	Section B: Viruses, Epidemiology, and Virus-Vector Interactions	*Judy Brown & Jeff Shapiro*
9:15 a.m.	Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods	*Phil Stansley*
9:45 a.m.	Section D: Natural Enemy Ecology and Biological Control	*Kevin Heinz & Oscar Minkenberg*
10:15 a.m.	BREAK	
10:30 a.m.	Section E: Host Plant Resistance, Physiological Disorders, and Host Plant Interactions	*Eric Natwick & Alvin Simmons*
11:00 a.m.	Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems	*Peter Ellsworth, John Norman & Dennis Kopp*
11:30 a.m.	Conclusions and Closing Remarks	*Tom J. Henneberry & Nick C. Toscano*
11:45 a.m.	ADJOURN	
1:00 p.m.	Working Group Meeting (Porthole Room)	

Immediately following the Working Group meeting, the PPRC will meet.

Sections A & B will meet concurrently on January 28th from 2:00 p.m.-5:00 p.m.

SECTION A: ECOLOGY, POPULATION DYNAMICS, AND DISPERSAL
(LOCATION: PACIFIC BALLROOM A)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*David N. Byrne & Larry Godfrey*
The Imperial Valley Whitefly Production System		*Allen, J. C. & C. C. Brewster*
Mapping the Imperial Valley Agricultural System from Satellite Data		*Brewster, C. C. & J. C. Allen*
Field Dispersal by *Bemisia tabaci*		*Byrne, D. N.*
The Effects of Daily Removal of Cotton Blooms on Plant Growth and Infestations of the Silverleaf Whitefly		*Flint, H. M., D. Hendrix, M. Salvucci, & S. Crafts-Brandner*
Velvetleaf: A Possible Candidate for Enemy Free Space in Desert Agricultural Systems		*Gruenhagen, N. M. & T. M. Perring*
Host-Location Flight Behavior of *Bemisia*		*Isaacs, R.*
Partial Life Table Studies of *Bemisia* in Cotton Fields Subject to Different Management Strategies		*Naranjo, S. E., P. C. Ellsworth & J. W. Diehl*
Effects of Insecticide Applications on *Bemisia argentifolii* (Homoptera: Alayrodidae) Densities, Honeydew Production, and Cotton Yields		*Yee, W. L., N. C. Toscano, D. L. Hendrix & T. J. Henneberry*

SECTION B: FUNDAMENTAL RESEARCH--BEHAVIOR, BIOCHEMISTRY, BIOTYPES, MORPHOLOGY, PHYSIOLOGY, SYSTEMATICS, VIRUS DISEASES, AND VIRUS VECTOR INTERACTIONS
(LOCATION: PACIFIC BALLROOM B)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*Judith K. Brown & Jeffrey P. Shapiro*
A DNA Sequence Database for Identification and Epidemological Studies of the Subgroup III, *Geminiviridae*		*Brown, J. K.*
The Defense Response of Tomato to Silverleaf Whitefly Feeding		*Puthoff, D., L. L. Walling & T. M. Perring*
Microdynamics of Whitefly Feeding		*Cohen, A. C.*
Feeding Behavior of Adult *Bemisia argentifolii* on Host and Non-Host Plants		*Walker, G.*
Identification of the *Bemisia argentifolii* Feeding Behavior that Results in Inoculation of Lettuce Chlorosis Virus (LCV)		*D. D. Johnson, G. Walker & R. Creamer*
Why Polyphenism is Important in Polyphagous Whitefly? Why Whiteflies are White? The Relationship of these Behaviors by the Silverleaf Whitefly and Greenhouse Whitefly		*Neal, J. W.*
Role of Trehalulose Synthesis in the Silverleaf Whitefly		*Salvucci, M. E.*
Technique for Culture of Larval *Bemisia argentifolii*		*Davidson, E. W.*
Differential Gene Expression: A Comparison of the Silverleaf Whitefly and Sweetpotato Whitefly Using Differential RNA Display		*LeVesque, C. S., T. M. Perring & L. L. Walling*
Use of Satellite DNA Sequences as Species-Specific Probes for *Eretmocerus* and *Encarsia* Parasitoids		*Heilmann, L. J.*

Sections C & D will meet concurrently on January 29th from 8:00 a.m.-12:30 p.m.

SECTION C: CHEMICAL CONTROL, BIORATIONALS, AND PESTICIDE APPLICATION TECHNOLOGY (LOCATION: PACIFIC BALLROOM A)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*John C. Palumbo & Philip A. Stansly*
Update on Monitoring Insecticide Resistance in SLWF Populations in California		*Toscano, N. C.*
Performance of Non-Conventional Insecticides on Sucking Insects Infesting Cotton in Egypt		*Moawad, G. M. & Z. H. Zidan*
Acylsugar Esters from Natural Extracts of *Nicotiana* and Similar Synthetic Analogs Against Silverleaf Whitefly in Field Trials with Cotton		*Akey, D. H.*
EXP 80667A - An Experimental Systemic Insecticide Against SLWF on Cotton		*Chu, C. C.*
RESCATE 200 (ACETAMIPRID) Performance Against SLWF in Mexicali Valley		*León-López, R. & R. Tafoya*
Observations on Detur Applied to Hibiscus		*Fox, C. A.*
Deposition of Tracer Dye on Paper Targets to Evaluate Application of Foliar Sprays		*Stansly, P. A. & T. X. Liu*

SECTION D: BIOLOGICAL CONTROL (LOCATION: PACIFIC BALLROOM B)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*Oscar Minkenberg & Kevin M. Heinz*
Natural Enemy Refuge Plants and the Establishment of Exotic Parasitoids		*Roltsch, W. J.*
Alfalfa & Other Host Plants as Reservoirs of Native and Introduced Parasitoids in Desert Agroecosystems		*Hoelmer, K. A.*
Development of Host Range Tests for Predatory Arthropods as Biocontrol Agents		*Kirk, A. A. & H. M. A. Thistlewood*
Delphastus Systematics and Biological Control of Whitefly		*Pickett, C. H., W. J. Roltsch & K. A. Hoelmer*
Field Cage Evaluation of *Amitus bennetti*		*Joyce, A.*
Novel Method for Field Delivery of Parasitoids in BC-Based IPM		*Goolsby, J. A., M. A. Ciomperlik & L. E. Wendel*
Biological Control-Based IPM of *Bemisia* in the Lower Rio Grande Valley of Texas		*Ciomperlik, M. A., J. A. Goolsby & L. E. Wendel*
Seasonal Inoculative Biological Control with Parasitoids of *Bemisia* Infesting Cantaloupe in the Imperial Valley of California: A Report of 3 Years of Investigations		*Simmons, G. S., K. Hoelmer, R. Staten, T. Boratynski & E. T. Natwick*
Field Evaluations of Whitefly Parasitoids Evaluated		*Minkenberg, O.*
Interspecific Interactions Among *B. argentifolii* Parasitoids		*Bográn, C. E.*
Interactions Between *Encarsia* pergandiella and *Eretmocerus* sp.: Host Stage Discrimination for Male Production		*Jones, W. A.*
Host Plant Specific Foraging Behavior of Selected Parasitoids of *Bemisia argentifolii*		*Heinz, K. M.*
Deraeocoris pallens Reuter, *Orius niger* Wolf, and *Campilomma unicolor* Poppius (Homoptera: Aleyrodinea) as Predators of *Bemisia* Nymphs		*Gerling, D., V. Kravchenko & M. Guershon*
Entomopathogenic Fungi as Biocontrol Agents on *Bemisia argentifolii*		*McMillan Jr., R. T.*

Sections E & F will meet concurrently on January 29th from 2:00 p.m.-5:00 p.m

SECTION E: CROP MANAGEMENT SYSTEMS AND HOST PLANT RESISTANCE
(LOCATION: PACIFIC BALLROOM A)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*Eric T. Natwick & Alvin M. Simmons*
A Search for Silverleaf Whitefly Resistance Traits Among Pima Genotypes		*Percy, R. G.*
Resistance of Lycopersicon Accessions to the Silverleaf Whitefly		*Muigai, S. G. & D. J. Schuster*
Interaction Between Silverleaf Whitefly and Cantaloupe		*Riley, D. G.*
Insect Adaptation Effects on Plant Resistance to Silverleaf Whitefly		*van Giessen, W. A. & D. M. Jackson*
Is Breeding for Resistance to the Silverleaf Whitefly a Viable Pest Management Approach?		*Jackson, D. M., W. A. van Giessen & M. W. Farnham*
Effects of Cotton Cultivar and Insecticide Treatments on Silverleaf Whitefly Infestation and Parasitism		*Natwick, E. T., C. C. Chu, G. Simmons, A. C. Cohen & D. Brushwood*
Delay of Geminivirus Dissemination in Tomato Fields by Interfering with *Bemisia tabaci* Adults		*Hilje, L.*

SECTION F: INTEGRATED TECHNIQUES, APPROACHES, AND PHILOSOPHIES
(LOCATION: PACIFIC BALLROOM B)

WELCOME AND INTRODUCTIONS	*Co-Chairs:*	*Dennis D. Kopp & John W. Norman Jr.*
IPM Actions & Practices in Cotton Fields from the Mexicali Valley (3rd Year)		*Leon-Lopez, R.*
Analysis of 3 Year Actions on SLWF Management in the Mayo Valley		*Valenzuela-Lagarda, J.*
Research Review on Silverleaf Whitefly in NW Mexico		*Martinez-Carrillo, J. L., J. J. Pacheco-Covarrubias*

Appendix D

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TABLE A. Ecology, Population Dynamics, and Dispersal[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
A.1 Define biology, phenology, and demography of SLWF on greenhouse, field crop and wild host plants.	Systematic study of SLWF on cultivated and weed hosts, seasonal time of occurrence, habitat.	Identify preferred hosts, determine seasonal distribution, determine developmental, reproductive and mortality rates of SLWF on crop and weed hosts.	Continue demographic studies, determine relationships between crop sequencing, preferred hosts and population dynamics.	Determine seasonal contribution of cultivated and wild host plants to SLWF population dynamics.	Describe role of cultivated and wild host plants on the population dynamics of SLWF, identify weak links in seasonal biology.
A.2 Develop efficient SLWF sampling plans for research and decision making purposes.	Determine spatial distributions, define sample units for immature and adult SLWF, examine variance components, optimize sample number and allocation.	Formulate sampling plans, determine relationship between sampling techniques for adults and crop infestations, evaluate feasibility of a standard sampling technique.	Continue development and refinement of sampling plan, implement and test protocols, develop remote sensing tools to estimate regional population levels.	Continue testing and implementation of sampling plans in terms of reliability and efficiency, continue development of remote sensing tools.	Finalize sampling protocols.
A.3 Develop economic thresholds for SLWF in relation to feeding damage, honeydew production and virus transmission.	Determine components of yield and quality affected by SLWF feeding, virus transmission and honeydew production on crop studied.	Determine and quantify relationships between SLWF population density and plant yield and quality, formulate economic thresholds in relation to sampling protocols.	Continue quantification of relationships between SLWF density and yields and quality, continue formulation of economic thresholds with refined sampling protocols.	Perform economic analyses, evaluate economic thresholds in crops studied.	Continue economic analyses.
A.4 Develop and test population models to describe and predict SLWF dynamics.	Determine model goals, define preliminary model structures and identify data needs, evaluate existing biological information.	Develop relationships between SLWF biology and crop phenology and crop sequencing. Integrate SLWF, natural enemy, and plant components into simulation models.	Continue model construction, evaluate data needs, begin evaluation of model predictions of SLWF population development.	Validate simulation models under field conditions, analyze model behavior.	Identify existing information gaps in insect and plant interactions.
A.5 Determine factors influencing SLWF dispersal and impact of dispersal on population dynamics in greenhouse, field crop, and weed host systems. (Combined with A.6 based on Year 1 recommendations.)	Determine relationships between crop phenology, crop status and SLWF dispersal.	Determine biological factors (physiology, behavior, sex, etc.) influencing dispersal.	Determine effects of weather parameters on dispersal.	Examine interrelationships of crop production methods and SLWF dispersal.	Summarize information on research progress on SLWF dispersal and propose needed research.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

TABLE B. Fundamental Research - Behavior, Biochemistry, Biotypes, Morphology, Physiology, Systematics, Virus Diseases, and Virus Vector Interactions[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
B.1 Studies of feeding behavior: sensory receptors, ultrastructure, morphology, digestive physiology; intra- and interspecific competition.	Begin studies of ultrastructure, morphology; analyze feeding and digestive processes; begin studies of parameters influencing competition.	Continue studies from Year 1; characterize feeding by-products and digestive enzymes; determine influence of host plant morphology, physiology, ecology and phenology on SLWF feeding behavior and competition.	Continue in-depth studies begun earlier; investigate relationship between endosymbionts and nutrition; use feeding monitor to screen for host resistance and response to residues of pesticides and natural products.	Continue research begun earlier; identify weak links for management-based research.	Continue basic research; investigate approaches for interrupting feeding and digestion, and reducing competitive abilities.
B.2 Studies of biochemistry, physiology, nutrition, development and reproduction, genetics and genetic diversity.	Identify temperature tolerances; begin study of host influences (i.e., water balance, osmotic concentrations, nutrients) on SLWF; begin studies of nutritional physiology, reproductive physiology, ploidy level.	Continue fundamental studies begun in Year 1; expand studies of genetic diversity; identify areas for continued emphasis.	Continue basic studies; identify potential weak links for further research: i.e., genetic and physiological bases for host selection, habituation, switching, etc.	Continue basic studies; investigate approaches for interrupting or altering key biological processes.	Continue basic studies; implement strategies for interfering with key processes; assess potential for further development.
B.3 Studies to discover and analyze diagnostic characteristics of SLWF, including component taxa, and to determine biological and genetic basis for development of biotypes, host races, and species.	Collect SLWF taxa and characterize their validity using morphological, molecular, biochemical, and biological studies to distinguish genetically different populations; develop voucher protocol for preservation of morphological and molecular information; establish centralized molecular services.	Continue systematic analysis of SLWF; provide molecular services based on information derived from Year 1.	Continue systematic analysis of SLWF; develop rapid identification systems.	Finish analysis of SLWF character development of rapid identification system.	Provide synthesis of diagnostic analysis of SLWF taxa; relate results to other fundamental approaches; continue molecular identification services; finish development of rapid identification system.
B.4 Develop systematic analysis of the genus *Bemisia* utilizing various methods.	Begin analysis of all species of *Bemisia* using at least morphological and DNA sequence analyses; develop collecting and preservation protocols; identify sources worldwide and begin collecting material for analysis.	Continue analyses of *Bemisia* species, defining characters using characters from morphological and DNA sequence studies; investigate value of supplementary methods (i.e., cuticular hydrocarbons, immunological assays, isozymes, symbiont associations, etc.)	Continue analyses of *Bemisia* species, define taxa and begin phylogenetic analysis.	Complete systematic analysis of *Bemisia* species; complete phylogenetic analysis of at least morphological and DNA sequence information.	Complete systematic analyses; validate supplementary methodologies.

B.5 Identify and define SLWF toxicogenic effects. Develop dsRNA and cDNA probe.	Characterize toxicogenic effects, cytology and EM.	Fractionate SLWF and affected plants. Isolate toxicogenic fractions. Characterize endogenous mediators, Use cDNA probe to screen biotypes.	Define affected plant target molecules and molecules mediating systemic response. Use probe to localize source of dsRNA.	Characterize toxicogenic molecules and mode of action. Utilize probes for field IDs.	Define mechanisms of plant resistance and integrate knowledge in developing IPM.
B.6 Characterize SLWF endosymbiote (SLWFe) influence on metabolism, host range, and biotype formation.	Treat SLWF with antibiotics and determine effects on growth, development and reproduction.	Develop methods for isolation and SLWFe and extraction of nucleic acid. Amplify specific SLWFe genes via PCR.	Analyze variability of SLWFe genome in different SLWF biotypes via RFLP, PFE and hybridization with SLWF dsRNA probe	Determine specific genes and gene products associated with SLWF metabolism.	Analyze progress and determine feasibility of pest management based on interruption of endosymbiotic relation.
B.7 Investigate etiology of diseases; biological and molecular characterization of causal agents; develop understanding of relationship; molecular probes for viral diseases; diagnostics and resistance; virus-vector specificity and interactions.	Collect and establish pure cultures; initiate transmission studies and biological characterizations, cloning and purification for these studies and antibody production, screening for resistance.	Continue with biological and molecular studies; continue cloning and characterization; begin antibody production. Develop detection and identification systems. Study virus-vector interactions: receptors, transmission, transformation, resistance.	Continue developing virus diagnostics; molecular comparisons of sequence data, relations; continue cloning and characterization; continue virus-vector studies. Develop diagnostic tests for epidemiological purposes; clones for (injured) resistance.	Develop strategies for engineered resistance; prototype isolates based upon molecular characterization and distribution studies; biological, molecular parameters, viral designations standardized; methods for identification; mechanisms of vector transmission.	Continue virus-vector studies; evaluate resistance studies: engineered and classified w/prototype isolates. Continue biological and molecular studies of new pathogens; viral taxonomy; standard-ize names.
B.8 Study epidemiological parameters: vector population dynamics; disease thresholds; identify sources of inoculum, distribution, severity, and prevalence of pathogens. Correlate efficiency of transmission with biotypes, diversity and parameters of cropping systems.	Initiate study of transmission efficiency, vector population dynamics, fecundity studies, host reservoir studies. Survey problem areas to identify key virus isolates; develop transmission thresholds for viruses.	Continue to investigate epidemiological parameters; begin to establish diagnostics; identify key isolates for in-depth characterization; study vector-host plant interactions.	Continue epidemiology studies; evaluate strategic management methods (i.e., sanitation programs based on inoculum sources); study vector-host-virus interactions in field; apply diagnostics.	Continue application of diagnostics to field epidemiology studies. Evaluate distribution, reservoirs using diagnostics; evaluate resistance in field studies.	Continue development, application of management strategies based on epidemiology studies. Transfer information for use in cropping systems, host free periods, recommenda-tions for long term disease management.
B.9 Study mating and oviposition behavior.	Study mating behavior in detail; determine possible role of sex pheromone; study role of mating in oviposition.	Determine factors, environmental and biological, that affect mating; determine factors affecting oviposition site selection and fecundity.	Develop methods for determining mating success, sperm transfer, fertilization, etc.; determine role of nutrition in oviposition and viability.	Identify factors that may be manipulated to manage or present mating; examine potential of attracticides and manipu-lation of crop production in reducing oviposition.	Exploit such factors in field trials to determine their potential in control methodology; quantify role of oviposition behavior in population dynamics.

B.10 Determine factors influencing host plant selection and host acceptance.	Determine nature of physical, environmental, plant host, physiological cues involved; investigate extent of semiochemical mediation in host finding.	Isolate, identify chemicals and other cues involved; continue studies of host selection and acceptance.	Develop bioassay methodology for quantifying semiochemical effects on SLWF behavior.	Determine interactions of semiochemicals with environmental factors, incl. natural enemies.	Determine potential for manipulating semiochemicals and other host-finding or acceptance cues as behavioral components in SLWF control systems.
B.11 Identify plant nutritional and defensive responses to SLWF and their effects on SLWF and natural enemies.	Identify proteins, enzymes, and natural products induced in plants by SLWF; examine influence of changes in nutrient levels on SLWF and enemies.	Isolate and characterize induced protein, enzymes, or compounds.	Determine effects on SLWF and evaluate as resistance mechanism; evaluate effects on SLWF natural enemies.	Identify source of defensive factors in plants and their targets in SLWF; continue studies of tritophic level interactions.	Target specific factors for genetic engineering of plant resistance.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

TABLE C. Chemical Control, Biorationals and Pesticide Application Technology.[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
C.1 Identify, for registration, new chemicals and formulations that effectively control SLWF.	Lab and field evaluation of chemicals with rates, combinations to identify promising materials.	Expand field research with best combinations and application methodology.	Evaluate new chemicals in relation to stage of insect killed, economic threshold, and effect on beneficials.	Determine chemical effects of SLWF populations, increased yields, and quality of crops to provide data useful for registration purposes.	Formulate control strategy based on research progress that indicates rates, gal/ acre, frequency of applica-tion, and associated secondary pests.
C.2 Identify, for registration, biorational materials with new modes of action.	Initiate studies with oils, soaps, natural products, both organic and inorganic, to determine efficacy.	Conduct field studies to determine coverage, rates, gal/acre, etc., to provide data useful for registration purposes.	Expand studies with best materials with highest potential. Evaluate efficacy, timing, alternatives with other chemicals.	Develop alternating sequences between chemicals and biorationals for best SLWF management system.	Implement alternating sequence management systems to prevent resistance.
C.3 Develop application schedules, methods in relation to economic thresholds.	Determine SLWF population levels under various chemical and biorational control systems.	Determine relationship between SLWF populations, chemical control, and yield for economic threshold.	Identify specific optimum controls in relation to SLWF economic threshold.	Validate estimated economic threshold concept and insecticide use patterns.	Develop protocols for SLWF economic thresholds and insecticide use on as-needed basis.
C.4 Insecticide resistance studies.	Collect strains in different locations, crops, etc., and establish resistance patterns and levels.	Develop standardized insecticide resistance monitoring systems.	Determine insecticide dose relationships, discriminating doses, and hormoligosis.	Initiate study to determine mode of action of insecticides.	Initiate studies to develop insecticide resistance management and outline area-wide pesticide rotation systems.
C.5 Genetics of insecticide resistance in SLWF.	Collect strains in different locations, crops, etc., and establish resistance patterns and levels.	Begin construction of isogenic resistant and susceptible strains through back-crossing and selection.	Use RAPD and restriction mapping techniques to ID markers associated with resistance genes.	Isolate individual resistance genes in backcrossed lines and determine cross-resistance relationships.	Initiate studies to develop insecticide resistance management and outline areawide pesticide rotation systems.
C.6 Develop methods for application or delivery of materials to improve control.	Compare methods of application, e.g., aerial, ground, high volume air, and others for estimates of plant (especially underleaf) coverage. Determine spray deposition (µg a.i./cm^2) and coverage for different application techniques, e.g., aerial, ground, electrostatics, chemigation, air carrier sprays, etc. Relate efficacy to spray deposition and coverage.	Evaluate modified spray equipment, boom drops, nozzles, and arrangements; and chemigation.	Determine efficacy, with best coverage application equipment.	Verify best of the current state-of-the-art application equipment.	Determine need for continued research.

C.7 Evaluate application methodologies for impact on natural enemies and SLWF interactions.	Determine baseline information on existing natural enemies-quality and quantity.	Determine effect of various chemicals and biorationals on natural enemy populations and associated minor pests.	Compare rates, combinations, application technology on natural enemy populations.	Determine optimum and best materials and application technology to develop maximum natural enemy conservation.	Develop standard protocols for chemical control and natural enemy integrated systems for best control in relation to economic thresholds.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

TABLE D. Biocontrol[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
D.1 Determine effects of indigenous natural enemies on regulating SLWF populations.	Survey for and identify key natural enemies in various habitats and seasons.	Continue survey; culture and study reproductive biology of beneficial species.	Continue biological studies; determine effectiveness of species under various habitat and weather conditions.	Determine interactions among SLWF, host plants and natural enemies.	Examine species and methods for exploiting selected natural enemies in crop systems.
D.2 Develop methods for enhancing habitats with refuge plantings to conserve natural enemies..	Establish refuge plantings; colonize parasitoids; sample for and identify native natural enemies.	Continue sampling; test inoculative parasitoid releases; determine SLWF/ parasitoid interactions.	Evaluate refuge plantings as field insectaries on larger scale.	Continue evaluation of most promising methods.	Implement and evaluate large scale conservation management systems.
D.3 Identify new natural enemies in areas of SLWF origin; foreign explora-tion, importation and release.	Collect, identify and import exotic natural enemies from specific habitats.	Continue collections; assess biology and host relations; develop rearing techniques.	Continue collections; determine habitat "fit" for each candidate; assess interactions with native species.	Conduct host range tests; rear, release promising natural enemies.	Determine adaptation of introductions and effects on SLWF populations.
D.4 Determine natural enemy host selection processes and mechanisms.	Study mechanisms involved in natural enemy host foraging.	Study efficiency of host foraging mechanisms.	Determine factors affecting interactions of host foraging mechanisms, hosts and host plants.	Determine potential of implementing host forag-ing mechanisms in SLWF population management.	Implement methodology developed into SLWF management systems.
D.5 Inoculate/augment parasite and predator populations through propagation and release.	Identify best candidates for augmentation based on selected attributes.	Develop laboratory rearing procedures for select species.	Conduct tests on technical feasibility of inoculating/ augmenting predator/ parasite populations for suppression of SLWF.	Develop mass propagation and release procedures for selected species.	Conduct areawide suppression trials and continue developing the mass propagation, distribution, storage and release technology.
D.6 Determine effects of pathogens on regulating SLWF populations.	Determine role in specific crops; develop culturing techniques.	Screen candidates for efficacy and effects on non-target organisms.	Evaluate for efficacy and persistence in small plots; develop formulations, evaluate for micotoxins.	Monitor dispersal and begin large scale field evaluations. Evaluate persistence and develop protocols for suppression of SLWF populations.	Expand field evaluations and begin technology transfer.
D.7 Evaluate compatibility of pesticides with SLWF natural enemies.	Laboratory screening for effect of pesticides on selected SLWF natural enemies and develop baseline data.	Survey for geographic variation to pesticide exposure and select natural enemies with pesticide tolerance; identify pesticides that are compatible with natural enemies.	Challenge selected natural enemies to develop resistant strains.	Limited field trials to determine effectiveness and survival of resistant natural enemy strains.	Evaluate potential in large scale field trials.

D.8 Systematics of predators, parasites and pathogens.	Finalize taxonomist network; inventory species, literature, collections; survey NA fauna and flora; establish common curation techniques.	Continue survey; identify and voucher exotic material; implement protocols.	Review critical genera; establish limits of relevant species worldwide.	Describe new taxa, prepare keys, characterize phylogenetic relationships.	Conduct molecular, biochemical, or other studies on target taxa.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

TABLE E. Crop Management Systems and Host Plant Resistance[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
E.1 Determine effect of traditional crop production inputs on SLWF population development.	Investigate effects of irrigation, fertilization, and plant growth characteristics on SLWF population dynamics.	Identify crop production methodology that may be a factor in SLWF population development.	Determine mechanisms involved in crop production factors which greatly affect SLWF biology, behavior, etc.	Determine possibility of exploiting or manipulating crop production methods as a factor in SLWF management.	Develop methods that are grower acceptable to minimize SLWF damage and maximize profits.
E.2 Determine temporal and spatial effects of host plants on SLWF populations and dispersion.	Determine SLWF reproduction, population development and factors affecting them on selected major crops and weeds.	Identify preferred cultivated and weed hosts and contribution to overall population density and SLWF dispersion.	Determine interactions of cultivated host sequences and weeds on SLWF population development and movement.	Determine potential of manipulating cultivated host sequences during growing season to reduce SLWF populations.	Develop best strategy for cultivated host sequences that will minimize SLWF damage to crops.
E.3 Determine effect of colored mulches, trap crops, intercropping, row covers, and other innovative cultural practices as potential SLWF control methods.	Identify cultural practices in crop production systems affecting SLWF biology and behavior.	Determine potential effectiveness of innovative cultural practices on SLWF behavior.	Conduct studies to determine potential of cultural practices to affect SLWF population development in the field and affect yield.	Identify cultural factors with greatest potential for adversely affecting SLWF population development and improve yield.	Incorporate best potential factors into system and determine effect on SLWF and crop net returns.
E.4 Develop reproducible evaluation techniques to isolate resistant germplasm.	Determine rapid, reproducible evaluation techniques for identifying resistance germplasms.	Apply developed methodology to identify resistant germplasm.	Use improved evaluation techniques to identify resistance mechanisms.	Begin to characterize resistance mechanisms and to identify chemical/ morphological components.	Continue characterization of resistance mechanisms
E.5 Identify resistant germplasm to SLWF and associated viruses and plant disorders.	Collect potential sources of resistance germplasm.	Screen and identify resistance sources.	Quantify effects of resistance characters on SLWF, virus, and associated plant disorders.	Determine interaction of selected plant types and SLWF populations in the field.	Continue evaluation of selected plant types for management of SLWF.
E.6 Conduct plant breeding studies to select SLWF resistant plant germplasm.	Conduct plant breeding studies to incorporate resistance into acceptable plant types.	Continue plant breeding experiments to produce highest resistance levels.	Begin to transfer resistance factors into improved plant types.	Continue the transfer program.	Continue the transfer program.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

TABLE F. Integrating Techniques, Approaches and Philosophies.[1]

Research Approaches	Year 1	Year 2	Year 3	Year 4	Year 5
F.1 Risk assessment.	Identify a national evaluation panel to characterize risk assessment information needed for producers and the environment. Design risk assessment procedures for whitefly virus.	Interface with objectives for spatial analysis, network activity, ecosystem models and design risk assessment procedures for whitefly.	Operate risk assessment system. Validate risk assessment estimates. Expand to other pests. Collate multi-location results. Interface with IPM programs and crop loss assessment.	Technology transfer to existing institutional responsibility.	Support risk assessment system and develop management procedures.
F.2 Spatial analysis and GIS.	Establish a national center to coordinate a national network of spatial analysis with GIS capabilities. Determine information needs for SLWF.	Establish a network of user-information coupling participants. Input of spatial data. Look at other pest problems.	Run and validate system performance. Interface system with ecosystem modeling activity. Interface system with existing IPM networks.	Transfer technology to existing institutional programs. Combine GIS data bases.	Operate system under new framework of administration. Troubleshoot activities.
F.3 Ecosystem modeling.	Establish a National ecosystem model panel to identify scale and attributes of components. Interface with network.	Develop site-specific models in all participating states site-specific models. Define appropriate resolution of modeling activity. Address other pest problems.	Interface with spatial analysis. Couple crop model with spatial data.	Use model with spatial analysis capability.	Transfer activity to state institutions and assist in specific activity.
F.4 Networks.	Test and run NBCI bulletin board. Expand network to international dimension for biological control information exhibition. Expand written materials and workshop presentations. Bring GIS up on networks.	Teleconferences on SLWF nationally. Expand to agricultural ecosystem management. Coordinate GIS with networks.	Teleconference SLWF program internationally. Begin transfer of GIS to extension applications.	Continue to operate system. Continue transfer of GIS to extension.	Transfer national activities to permanent institution support.

F.5 IPM program implementation.	Identify existing taskforce or action groups and link them into a communication network; written, electronic, radio and conferences. Support and expand information network, newsletters, news articles, video conferences. Interface with appropriate National and State crop programs.	Develop procedures for data capture at local sites throughout the country and expand to other significant pests. Access spatial data and ecosystems models. Incorporate programs with existing IPM programs.	Maintain system and continue to expand other pests.	Maintain system.	Transfer system to permanent support such as State Department of Agriculture, Cooperative Extension Service, Commodity groups, private groups and troubleshoot system.

[1] Source: USDA. 1992. Conference Report and 5-Year National Research and Action Plan for Development of Management and Control Methodology for the Sweetpotato Whitefly. United States Department of Agriculture, Agricultural Research Service, ARS-107, 165 pp. National Technical Information Service, Springfield, Virginia.

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